HARDWARE REQUIREMENTS DOCUMENT (HRD) FOR THE MUSCLE ATROPHY RESEARCH AND EXERCISE SYSTEM (MARES) OF THE HUMAN RESEARCH FACILITY (HRF)

LS-71053-1

6 December, 2002

National Aeronautics and Space Administration

Lyndon B Johnson Space Center
Houston, Texas 77058

european space agency

european space research and technology centre
Noordwijk, The Netherlands

CDR Version: issue 3, revision 3
Hardware Requirements Document (HRD) for the
Muscle Atrophy Research and Exercise System (MARES) of the Human Research Facility (HRF)

NASA APPROVAL	ESA APPROVAL
HRF Project Manager ***(D. GROUNDS Ph.D.)***	MSM-GM Division Head ***(W. RIESSELMANN)***
HRF Hardware Development Manager/SM4 ***(D. BAUMANN)***	MSM-GMP Section Head ***(J. C. IVES)***
HRF Project Scientist ***(S. SCHNEIDER Ph.D.)***	MARES Project Manager ***(J. CASTELLSAGUER)***
NASA-JSC Crew Representative CB	MARES FST Co-ordinator ***(Dr. P. Barattini)***
US FST chairwoman *(Prof. P. CLARKSON)*	MSM-G Product Assurance Manager ***(T. SGOBBA)***

*** CONTRACTORS APPROVAL PAGE ***

CDR Version: issue 3, revision 3
Hardware Requirements Document (HRD) for the **Muscle Atrophy Research and Exercise System (MARES)** of the Human Research Facility (HRF)

(Mete Yalcinkaya)
MARES Project Lead

(A. Tomàs)
Project Manager

(Jerry McDonald)
UF-1 HRF Hardware Manager

(M. Pastor)
Company Manager

(Jim Hoge)
HRF Systems Engineering and Integration Manager

(E. Garcia)
Product Assurance manager

(Elizabeth Patnovic)
HRF Program Manager

Prepared by: Lockheed Martin Engineering and Sciences (LMES)
Houston, Texas for the
National Aeronautics and Space Administration,
Johnson Space Center
Contract No. NAS9-19100

NTE SA

Prepared by: NTE S. A.
Barcelona, Spain
for the
European Space Agency,
ESTEC

Document change record

Document reference: LS-71053-1

Issue	Rev.	Date	Sections affected	Remarks
1	0	28-Nov.-97	all	first version from NTE
2	0	3-Feb.-98	all	ESTEC version to preTEB
2	1	20-March-98	Almost all sections.	Update accord. to TEB, HRF, FST, comments
2	2	9-April-98	Preface, 1.2, 2.1to2.4, 3.1.2.1.1.8&10, 3.1.2.2.5.2.2.1, 3.1.5.1.1.3, 4.1, 5.9 & 8.1.	RFQ version. Updated accord. to additional TEB comments, and editorial.
2	3	26-Aug.-98	3.1.2.1.3.4.3, 3.1.2.2.1.x, 3.1.2.2.2.x, 3.1.2.2.3.1.3, 3.1.2.2.3.2.x, 3.1.2.2.3.3.x, 3.1.2.2.3.4.x, 3.1.2.2.3.5.x, 3.1.2.2.3.6.2.1, 3.1.2.2.3.7.4, 3.1.2.2.3.10.1, 3.1.2.2.3.12, 3.1.2.2.4.3, 3.1.4.1, 3.1.4.2.1.1, 3.1.5.1.1.4, 3.1.5.1.2, 3.1.5.2.1&2,	Contract version. Updated accord. to NTE non-compliance's in their proposal.
3	0	-May.-01	General changes	CDR version. Updated according CDR conclusions
3	1	2-Aug.-01	2, 3.1.2.1.2.3, 3.1.2.1.6.1, 3.1.2.2.2.2, 3.1.2.2.3.5.1/5, 3.1.4.3, 3.1.5.2.1, 4.1, 4.2, 4.4.4, 5.10.1.2, 5.11, 7.2, 8.2	18798 & DGCS latest versions, Corona, and few corrections
3	2	6-Sept.-01	3.1.5.2.1	Two new PIRNs

Document reference: LS-71053-1

Latest version:

3	3	6-Dec.-02	2.1, 3.1.2.1.4, 3.1.4.1, 3.1.4.2, 3.1.5.1.1.6, 3.1.5.1.1.9, 3.1.5.1.4, 3.1.5.2	New ISS i/f's

Approval:

NASA-HRF Hardware Development Manager/SM4
(D. Baumann)

ESA MARES Project Manager
(J. Castellsaguer)

LM-HRF MARES Project Lead
(Mete Yalcinkaya)

NTE Project Manager
(J. Mas)

NTE Technical Manager
(A. Tomàs)

PREFACE TO MARES HRD

This document was jointly prepared by NTE S.A. for the European Space Agency and by Lockheed Martin Engineering and Sciences (LMES), for the National Aeronautics and Space Administration (NASA) Lyndon B. Johnson Space Center (JSC) under contract NAS9-19100, sub task order (STO), Human Research Facility (HRF) Utilization Flight (UF) - 3 Flight Hardware Development Management.

This document defines the hardware requirements for the Muscle Atrophy Research and Exercise System (MARES) which is part of the Human Research Facility (HRF) for the International Space Station (ISS).

This document is part of the contractual baseline between ESA and ESA's Contractor for MARES.

In the course of the project, the ESA's Contractor will use this HRD for the generation of the MARES Payload Specification, for review at PDR and CDR, and for hardware verification. This Specification shall comply with the HRD requirements and provide further detailed requirements, as necessary. HRF will use this MARES Payload Specification to generate further versions of the HRF HRD, as required by the internal HRF system.

This complex evolution of this document is because the ESA's contractual baseline should not change unless important events affect the project, but at the same time, the requirements need to evolve as the project progresses, and the HRF HRD needs to follow this evolution.

The binding technical requirements between NASA and ESA and between ESA and ESA's contractors is the latest version of this HRD, when signed by all parties.

LIST OF APPENDICES

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

ADAS	Ambulatory Data Acquisition System
ADP	Acceptance Data Package
BMU	Basic Motion Unit
CB	Crew Branch
CCB	Configuration Control Board
CIL	Critical Items List
C.o.G.	Centre of Gravity
COTS	Commercial-of-the-Shelf
CSCI	Computer Software Configuration Items
CR	Change Request
DCN	Drawing Change Notices
DR	Discrepancy Report
EEE	Electrical, Electronic, and Electromechanical
EGSE	Electrical Ground Support Equipment
ESA	European Space Agency
EUE	Experiment Unique Equipment
FMEA	Failure Modes and Effects Analysis
FRD	Functional Requirements Document
GIDEP	Government and Industry Data Exchange Program
GSE	Ground Support Equipment
HRD	Hardware Requirements Document
ISPR	International Standard Payload Rack
ISS	International Space Station
HRF	Human Research Facility
JSC	Johnson Space Center
LSA	Launch Structure Assembly
MARES	Muscle Atrophy Research and Exercise System
MGSE	Mechanical Ground Support Equipment
MIL-ER	Military Established Reliability
NASA	National Aeronautic & Space Administration
MVC	Maximal Voluntary Contraction
NSTS	National Space Transportation System
PCU	Profile Control Unit
PCUS	Profile Control Unit Software
PDA	Pre-delivery Acceptance Test
PEMS	Percutaneous Electrical Muscle Stimulator
PIA	Pre-installation Acceptance
PRD	Program Requirements Document
PSC	Physiological Signal ConditionerQA Quality Assurance
ROM	Range of Motion
S&MA	Safety and Mission Assurance
SDP	Software Development Plan
SIR	Standard Interface Rack
SMACAR	Safety and Mission Assurance Certification Approval Request Form
SMD	Strength Measurement Device
STO	Sub-Task Order

TBD	To Be Determined
TPS	Test Preparation Sheet
TRR	Test Readiness Review
UIS	User Interface Software
UOP	Utility Outlet Panel
VIF	Vibration Isolation Frame

1. INTRODUCTION

1.1 PURPOSE

The purpose of this Hardware Requirements Document (HRD) is to describe and delineate the methods by which the MUSCLE ATROPHY RESEARCH AND EXERCISE SYSTEM (MARES) for the International Space Station (ISS) Human Research Facility (HRF) shall be designed, developed, tested, and certified. This document was prepared based on the HRF HRD template, LS-71099 (BASIC, Jan. 98), as established by the HRF program.

1.2 SCOPE

The requirements established herein are applicable only to the MARES and its Ground Support Equipment. This hardware requirements document identifies unique, general construction, and environmental design requirements in sections three, four and five, respectively. Sections six and seven identify some specific test requirements. Section eight defines the Product Assurance and Safety requirements.

The MARES is a payload of the Human Research Facility (HRF) for the International Space Station (ISS). The governing document shall be SSP-57000, “Pressurized Payloads Interface Requirements Document”.

It is envisioned that MARES may be launched in stages. Each stage will be individually lifted to the Station where it will be assembled or reconfigured as the modules arrive. This document sets the requirements that are applicable to the complete final product.

APPLICABLE DOCUMENTS

The following specifications, standards, and publications are considered applicable to this HRD to the extent that they are each specifically called out in subsequent sections of this HRD.

It is the responsibility of the Contractor to acquire any of these documents from the Publication Department from the related organisation, if they were not in its technical library. This does not apply to the specific applicable documents listed under Publications, if requested, they may be made available to the Contractor.

2.1 SPECIFICATIONS

JSC-20793	Sept 85	Manned Space Vehicle Battery Safety Handbook.
MIL-S-7742	rev. B	General Specification for Screw Threads Standards, Optimum Selected Series
MIL-S-8879	rev. A	General Specification for Screw Threads, Control of Radius Root With Minor Diameter
MIL-S-33540		General Specification for Liquid Locking Compounds
NSTS-1700.7B	Jan.89	Safety Policy and Requirements for Payloads Using the Space Transportation System
NSTS-1700.7B ISS Addendum	Dec. 95	Safety Policy and Requirements for Payloads using the International Space Station
NSTS/ISS 18798B, incl. up to Change Packet 7	Sept. 97, Ch.Pack.7 (Oct. 2000)	Interpretations of NSTS/ISS Payload Safety Requirements
SN-C-0005	rev. C	Contamination Control Requirements for Space Shuttle Program
SSP-30233	Rev. E	Space Station Requirements for Materials and Processes
SSP-30245	rev. B	Space Station Electrical Bonding Requirements
SSP 30512C	rev. C	Space Station Ionizing Radiation Design Environment

SSP-30257:002	002	Space Station Program Utility Outlet Panel Standard Interface Control Document.
SSP-50313	G, 19 Sept. 2000	Display and Graphics Commonality Standards. Sect. 4: 25Jan.2000; Sect. 7: 26Jan.2000; Sect. 11: 26Jan.2000; Sect. 13: 27Jan.2000; App. B: 15Aug.2000; App. C: 15Jan2000; App. H 8Sept.2000
SSP-52000-IDD-ERP	C. Copy 4 21 Mar. 97	EXpedite the PRocessing of Experiments to Space Statixon (EXPRESS) Rack Payloads Interface Definition Document
SSP 57000E	Rev. E 1st Nov. 2000	Pressurized Payloads Interface Requirements Document
SSP-52005B	rev. B 28 Aug. 97	International Space Station Payload Flight Equipment Requirements and Guidelines for Safety-Critical Structures
SSP 50018	28 June 96	International Space Station (ISS) Standard Stowage Accommodations Handbook
JHB-5322	Rev. C	Contamination Control Requirements Manual

2.2 STANDARDS

JSC-23642	rev. B	JSC Fastener Integrity Program
ESA PSS-01-746	Iss. 1 June 93	General Requirements for Threaded Fasteners
JHB-8080.5	.5	JSC Design and Procedural Standards Manual
SSP-50005B	Aug. 95	International Space Station Flight Crew Integration

2.3 PUBLICATIONS

GPQ-010 + Change Not. 01	Issue 1, Revision 0	Product assurance requirements for ESA microgravity projects.

GPQ-010-PSA-101	Issue 1, Revision 0	Safety and materials requirements for ESA microgravity payloads (ISSA)
GPQ-010-PSA-102 + Change Not. 01	Issue 1, Revision 0	Reliability and maintainability for ESA microgravity facilities (ISSA)
LS-71000	Rev. A	Program Requirement Document for the Human Research Facility
LS-71001	Rev. A Nov. 25, 1996	Functional Requirements Document for the Human Research Facility
LS-71002	Jan. 96	HRF System Safety Program Plan for the HRF
LS-71010	Sept. 97	Fracture Control Plan for the Human Research Facility
LS-71011	Sept. 97	Acoustic Noise Control and Analysis Plan for Human Research Facility Payload and Racks
LS-71012	Sept. 97	Structural Analysis Plan for the Human Research Facility
LS-71016	Jan. 97	Electromagnetic Compatibility Control Plan for the Human Research Facility
LS-71018	Oct. 97	Electrical Power / Battery Control Plan for Human Research Facility
LS-71019	Dec. 97	Data System Architecture Definition for Human Research Facility
LS-71020	Appendix: 3.11.97	HRF Software Development Plan: Appendix only
MARES-SP-007-03-NTE	31.07.97	MARES Payload Software Specification
MAR-701-ESA/AK	4.D 23 March 1998	Science and Operations Evaluation Plan (SOEP)

COL-RIBRE-MA-0007-01	Draft B 31.08.97	CPAH, Columbus Payload Accommodation Handbook, Attached Pressurized Module (APM), Appendix A, Avionics Interfaces and Services
LS-40104	April 30, 1997	Neurolab Experiment, SRD for E049, E095, and E294. Studies of the Autonomic Nervous System.
LS-40105	May 28, 1997	Neurolab Experiments, SDD.

2.4 SELECTION OF SPECIFICATIONS AND STANDARDS

Specifications and standards necessary for design and development shall be selected in the following order of preference, except as otherwise specified in this document. The exact issue shown is to be used, unless otherwise specified in this document.

In case of conflict, the order of precedence shall be:

1. This Hardware Requirements Document
2. The three ESA publications quoted at the start of 2.3
3. SSP 57000
4. LS-71xxx documents from the Human Research Facility
5. NASA specifications and standards
6. Manned spacecraft criteria and standards
7. Federal specifications and standards
8. Military specifications and standards
9. Other governmental specifications and standards
10. Specifications released by nationally recognised associations, committees, and technical societies

3. UNIQUE DESIGN REQUIREMENTS

This hardware requirements section contains a general hardware description (for reference), and the hardware performance, load, physical (e.g., weight, envelope, etc.), and interface design requirements. The Certification Matrix found in Appendix A specifies the method of compliance for each of the following requirements/groups of requirements.

3.1 MUSCLE ATROPHY RESEARCH AND EXERCISE SYSTEM (MARES)

3.1.1 Description

The MARES is a physiological research facility, part of the HRF, to be used on board ISS.

MARES will be used to carry out research on muscle-skeletal, biomechanical, neuromuscular and neurological physiology, to study the effect of microgravity on the human being, and to evaluate the effect of the countermeasures to the Space environment induced physiological effects.

MARES can also be used to evaluate the performance of exercise tests protocols.

The MARES hardware is aisle mounted hardware (see Figure 3.1.1), capable of assessing the strength of isolated muscle groups, around specific joints or on complete limbs, by measuring and controlling the interrelation between speed and torque/force, as functions of time.

The principal components of the MARES, as identified in Table 3.1.1 - Hardware component list, shall be: main assembly consisting of main box and vibration isolation frame, chair, human interface adapters, launch structure assembly and a laptop computer for interaction with the crew. MARES shall also include the associated cables to connect the various MARES components together, to the ISS and to HRF.

Hardware Item	M/S	Notes
MARES Main Box	M	The Main Box will be structurally mounted to LSA for launch, but it will be deployed for on orbit use and stowed when not in use**.**
MARES Vibration Isolation Frame	S or M	
MARES Chair	S	The Chair will be stowed in a container for launch, but it will be mounted to the Main Box for on orbit use and stowed when not in use**.**
Human Adapters	S & M	Launched (together or separately) when required by flight experiments.
Laptop Computer	S	HRF provided
Launch Structure Assembly (LSA)	M	HRF provided
MARES Power Cable	S	HRF provided (if standard)
MARES Data Cable	S	HRF provided (if standard)

During transportation: M/S: M = Struct. Mounted S = Stowed in container

Table 3.1.1 - Hardware component list

During launch and landing, the Muscle Atrophy Research and Exercise System (MARES) elements will either be mounted on the Launch Structure Assembly (LSA) or stowed in launch containers. During on-orbit operations, Muscle Atrophy Research and Exercise System (MARES) will be deployed in the aisle. When not used on-orbit MARES will be stowed.

The MARES facility will be launched in different packages for easy launch accommodation. Once in orbit MARES will have to be assembled.

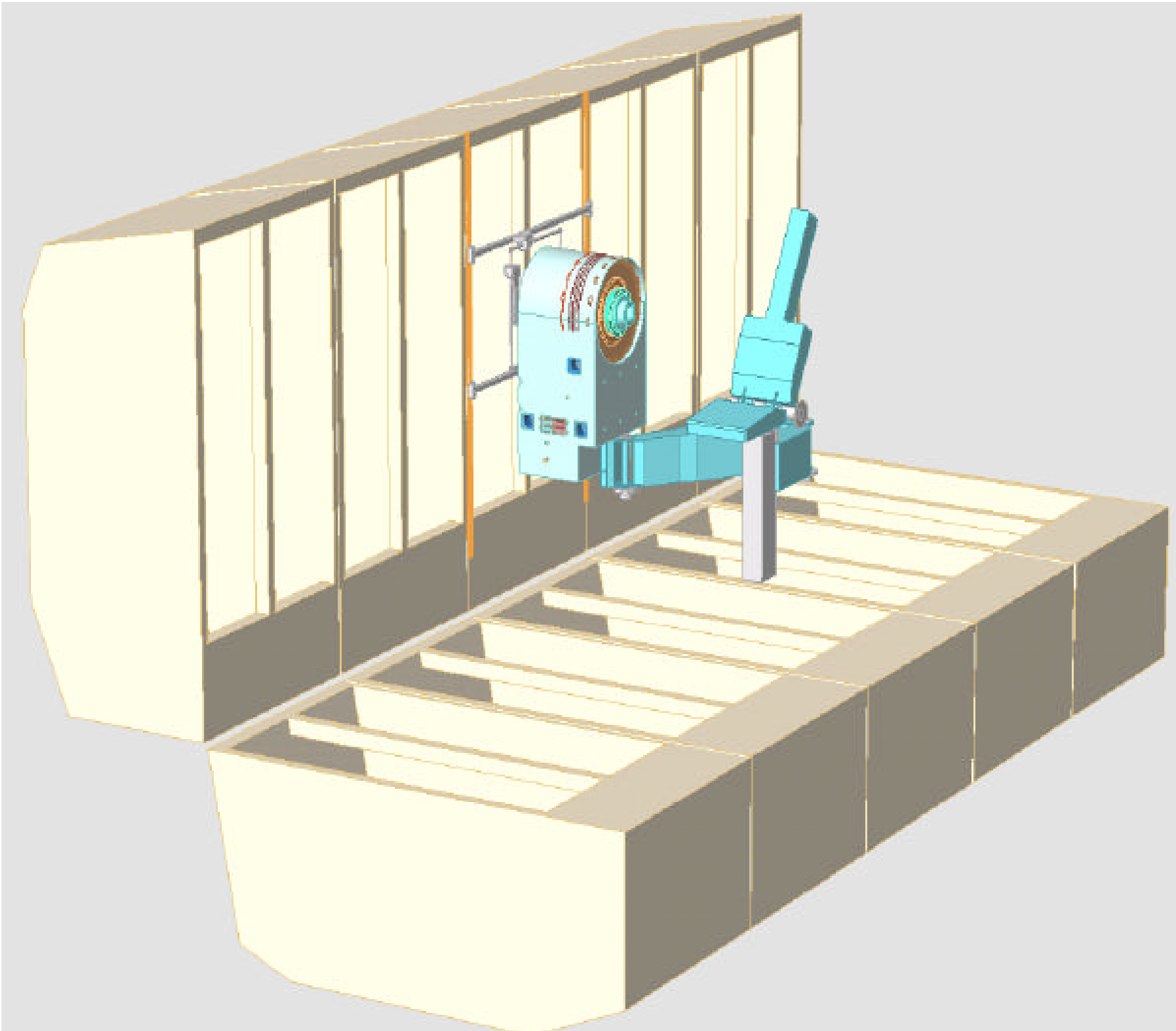


Figure 3.1.1 - Muscle Atrophy Research and Exercise System (MARES)

3.1.1.1 MARES Main Assembly

The Main Assembly for the Muscle Atrophy Research and Exercise System (MARES) will consist of the Main Box and the Vibration Isolation Frame.

The MARES Main Box will contain a motor, microcontroller, electronic subsystems, heat rejection systems and angular motion and torque sensors.

The controller receives data from the sensors on the motor axis and accordingly controls the motor, following profiles received from the Laptop Computer.

The motor mechanically drives the Human Adapter attached to its shaft.

As part of the main structure of the Main Box there are position adjustable mechanical and electrical end-stops that would physically prevent any human adapter to overpass the range of motion (ROM) limits of the subject's joints.

The MARES electronic subsystems mounted on the Main Box follow a modular design criterion for easy maintenance and to allow launch of MARES in lighter packages.

These electronic subsystems are described in the following paragraphs:

> The Power Electronics and Battery conditions the 120 VDC @ 10 A power supply provided either by the ISS UOP (Utility Outlet Panel) or by the Centre Aisle SUP in the COF module, and provides the different subsystems with power. The Power Electronics and battery protects ISS and MARES against unacceptable transients and changes in power supply / power demand.
>
> The Motor Drive Electronics supplies current waveforms to the motor coils according to the torque signal generated by the microcontroller.
>
> The Supervision Electronics conditions and monitors the signals from the different sensors within MARES (torque, position, temperature, switches), and sends them to the microcontroller. Hardwired logic in this Supervision Electronics will stop the motor and/or switch off the Power Supply if it monitors that there is a potentially hazardous situation.

The MARES Main Box includes fans to circulate the ISS module cabin air (in open loop) and cool down the different MARES subsystems.

The MARES Main Box interfaces mechanically with the ISPR (International Standard Payload Rack) seat tracks through the Vibration Isolation Frame (VIF). This VIF system contains passive mechanical isolators that minimise the disturbances to the ISS microgravity environment.

3.1.1.2 MARES Chair

The MARES chair will stabilise the subject during the exercises and minimise the influence of other muscle contractions on the measurement.

It is an articulated chair allowing the adjustment of the angle formed by seat and back and of its position with respect to the Main Box, and providing a comfortable fixation by means of shoulders and hip adjustable restraints.

The chair will directly mount to the Main Box through mechanisms that will allow positioning the subject's joint under study aligned to the motor shaft. In this way, the load path of the subject's exercise will stay internal to MARES. These mechanisms will cover the entire range of the eligible population.

3.1.1.3 MARES Human Adapters

The Human Adapters provide the connection points between the test subject and the dynamometer: motor shaft and Main Box, for all joint movements covered by MARES.

Together with the MARES Chair, the Human Adapters help to stabilise the subject and minimise the influence of other muscle contractions on the measurement. They also provide capabilities for the proper alignment of the joint axis of rotation to the dynamometer motor shaft.

The adapters will have to be stiff enough such that the angle of the joint under study meets the position and speed accuracy requirements.

The adapters will interface with the dynamometer output shaft with a quick disconnect mechanism.

When not in use, the Human Interface Adapters will be stowed.

3.1.1.4 Laptop Computer

On-board the MARES will use the HRF Portable Computer System (PCS) to act as the experiment controller and as the main interface with the crew for the control of the MARES system.

For use on ground, the MARES will replace the HRF PCS with a functionally equivalent portable computer, which will be part of the MARES Ground Support Equipment (GSE).

While being used in conjunction with the MARES, the HRF PCS computer will not have to run any additional application.

3.1.1.5 Launch Structure Assembly

For the launch of MARES in the MPLM, NASA will develop a launch structure assembly (LSA).

If Mares is launched in a different carrier, NASA will still provide an LSA with the same interface, as defined in this HRD.

3.1.1.6 MARES Power and Data Cables

The MARES will require a number of cables to interconnect its elements and to interface to the Station and to HRF. The cables to interface to external devices like Physiological Signal Conditioner (PSC) and Percutaneous Electrical Muscle Stimulator (PEMS) are not considered MARES elements.

HRF will provide CHIP harnesses wherever MARES can utilise them.

3.1.1.7 MARES Hard Disks

The MARES will require a number of hard disks for software and data storage and data interchange. These hard disks are not considered MARES elements.

3.1.2 Performance Requirements

This HRD uses LS-71001, “Functional Requirements Document for the Human Research Facility”, chapter 10.0, Item name: Strength Measurement Device, to derive the HRD performance requirements.

The MARES Certification matrix found in appendix A correlates each LS-71001 (FRD) functional requirement for the Strength Measurement Device (functional and technical) to the corresponding HRD (Section 3.1.2.1 and 3.1.2.2) performance requirement for MARES.

The applicability of LS-71001 is then limited to the extent that its requirements are repeated or modified in this HRD.

In cases where the FRD requirement has been allocated into a design requirement, that specific HRD requirement paragraph number is indicated. The annotation "DELETION" shall indicate that a functional requirement has not been implemented into the design and the traceability matrix comment field will indicate the reason.

In this Hardware Requirements Document all requirements are equally and simultaneously applicable, unless otherwise specified.

3.1.2.1 Functional requirements

3.1.2.1.1 Main functional requirements

3.1.2.1.1.1 Stimulus and measurement

The MARES shall be capable of applying complex programmable motion profiles and measuring the generated torque and velocity during tests on the agonist and antagonist muscle groups of the trunk and extremity joints.

3.1.2.1.1.2 Range of use

These motions shall cover maximal and submaximal isometric, isokinetic concentric, eccentric, and isotonic testing of the supported movements, throughout the entire safe range of motion defined in 3.1.2.1.1.3 of this HRD.

The definition of maximal performance with each movement has been based on available scientific publications and this definition is given for reference in 3.1.2.2.3.1 of this HRD.

For some of these movements, MARES will not cover the full torque/velocity range at maximal performance. MARES' capabilities are defined in 3.1.2.2.3.1 of this HRD.

Submaximal performance is delimited by the setting accuracy figures defined in 3.1.2.2.3 of this HRD.

3.1.2.1.1.3 Supported movements

The MARES shall be capable of performing torque/angular velocity and training measurements on the movements listed in Table 3.1.2.1.1.3 - MARES movements.

In this table, the terms "right or left extremity" mean that MARES shall cover this movement both, with the right and with the left extremity, although not at the same time. The terms "right and left extremities" mean that MARES shall cover this movement being performed by both extremities at the same time and with independent measurement of right and left limb forces (only used in linear movements).

The term "Whole Arm linear press" represent the multi-joint linear movement performed in overhead press (shoulder flexion at 180° when fully extended), in supine press (shoulder flexion at 90° when fully extended), and along intermediate straight lines between these two. Similarly with "Whole Leg linear press" for hip flexion between 0° and 90°.

These arm and leg linear movements shall support independent triaxial force/torque measurements.

MARES shall simultaneously cover the maximum Range of Motion (ROM) and the adjustment capabilities of the secondary joints, as indicated in Table 3.1.2.1.1.3 - MARES movements. This applies for the nominal subject positions (rest of the joints) as defined in 3.1.2.2.4 of this HRD.

Different subject positions from the nominal positions defined in 3.1.2.2.4 are allowed in MARES, but they may lead to a reduction of the ROM.

When the word "full" appears under ROM in Table 3.1.2.1.1.3 - MARES movements, this means that the defined range covers the full anthropometric range as defined in SSP 50005, ISS Flight Crew Integration Standard.

Movements 1 to 9 shall be angular. Movements 10 and 11 shall be straight linear.

Movements	ROM	Adjustable secondary joints
1. Ankle dorsi/plantar flexion, right or left extremity	111 ° (full)	Knee flexion from 0° (knee extended) to 90°
2. Knee flexion/extension, right or left extremity	115 °	Hip flexion from 0° (supine) to 90° (seated)
3. Hip flexion/extension, right or left extremity	150 ° (full)	Knee flexion from 0° (knee extended) to 90° . Male 95ile and 50ile. Female 95ile
	137°	Knee flexion from 0° (knee extended) to 90° . Female 5ile and 50ile. Male 5ile.
4. Wrist flexion/extension, right or left extremity	180 ° (full)	Elbow flexion from 0° to 90° (with corresponding shoulder extension from 0° to 25°)
5. Wrist supination/pronation, right or left extremity	240 ° (full)	Elbow flexion from 0° to 90° (with corresponding shoulder extension from 0° to 25°)
6. Wrist radial/ulnar deviation, right or left extremity	90 ° (full)	Elbow flexion from 0° to 90° (with corresponding shoulder extension from 0° to 25°)
7. Elbow flexion/extension, right or left extremity	150 °	Shoulder abduction from 0° to 30°, and Wrist prono-supination 0° and 90°
8. Shoulder flexion/extension, right or left extremity	190 °	Shoulder abduction 30°. Male 95ile.
	145º	Shoulder abduction 20º. Male 95ile.
	88º	Shoulder abduction from 0º to 10º. Male 95ile.
	138º	Shoulder abduction 30º. Female 5ile.
	65º	Shoulder abduction from 0 to 20º. Female 5ile.
9. Trunk flexion/extension	60 °	No adjustable secondary joint
10. Whole Leg linear press, right or left extremity right and left extremities	1000 mm.	Hip flexion from 0° (supine) to 90° (seated), and Hip abduction from 0° to 10°
11. Whole Arm linear press, right or left extremity right and left extremities	1000 mm.	Shoulder flexion from 90°(press) to 180°(overhead), and Shoulder abduction from 0° to 10°

Table 3.1.2.1.1.3 - MARES movements

3.1.2.1.1.4 Processing tools: T/a and T/V

The MARES shall be capable of providing processing tools to be able to display: peak torque vs. joint angles, average isometric torque over a certain time period at specific joint angles, as well as torque-velocity characteristics, throughout the entire safe range of motion.

3.1.2.1.1.5 Restraint

The MARES shall be capable of providing restraining devices to stabilise the subject and minimise the influence of other muscle contractions on the measurement.

3.1.2.1.1.6 Alignment

The MARES shall be capable of providing for the alignment of the device to the joint axes of rotation.

3.1.2.1.1.7 Processing tools: fatigue

The MARES shall be capable of providing processing tools to be able to assess fatigue over serial contractions.

3.1.2.1.1.8 Calibration

The MARES shall be capable of providing a calibration or validation method.

This calibration or validation method and the related tools (calibrator) shall form part of MARES, covering both, ground and flight operations.

It shall be possible to maintain and verify the MARES measurement and setting accuracy's for the whole foreseen life of MARES.

3.1.2.1.1.9 Data synchronisation

The MARES shall be capable of providing capabilities to be able to time synchronise the MARES data with other complementary analyses, including other data collected by the MARES data acquisition system, HRF laptop computer and the HRF Computer Workstation.

3.1.2.1.1.10 Deployment

The MARES shall be capable of being deployable within 10 minutes and portable from one module to the other of the ISS.

3.1.2.1.1.11 Stimulus

The MARES shall be capable of providing variable and quantifiable velocity or resistive torque during the profile motions. The velocity and resistive torque levels of the motion profiles shall be changeable on orbit as needed by the subject, or off-line from ground by the experimenter, up-loading the modified experiment.

3.1.2.1.1.12 Emergency egress

The MARES shall be capable of providing for emergency provisions to terminate any activity on the MARES.

3.1.2.1.1.13 Flight and ground operations

The MARES shall be capable of providing a design that has the capability to accommodate both 1-g and on orbit operation. For 1-g operation, MARES can be supplemented with the MARES GSE.

3.1.2.1.1.14 Science and Operations Evaluation Plan (SOEP)

The MARES shall be capable of performing all tests contained in MAR-701-ESA/AK, Science and Operations Evaluation Plan (SOEP).

Note: For some of these tests MARES and its GSE will need to be complemented with extra instrumentation i.e.: EMG/ECG amplifiers, etc. These instruments need to be made available by the Contractor during the project reviews, but they are not deliverables of the project.

3.1.2.1.2 MARES modes

MARES shall be able to control either: the torque applied at the motor shaft, the force/torque between the subject and the human adapter, their velocity, their position, or some mathematical relation between them that can include time as a parameter. Selecting one of the different MARES algorithms or modes and defining its parameters is the method to program these capabilities.

The MARES modes are formed by combinations of the Basic Motion Units (BMU) described in 3.1.2.1.2.2, which are used to build profiles, as described in 3.1.2.1.2.3, which are activated by a MARES experiment, as described in 3.1.2.1.2.4.

3.1.2.1.2.1 Basic definitions

3.1.2.1.2.1.1 Subject Torque/Force

Unless otherwise stated, in this HRD the terms Torque and Force, when used in the context of subject torque and force, respectively refer to the torque and force that could be measured in orbit at the connection of the moving limb with the corresponding human adapter. Torque being associated to angular movements and Force to linear movements.

In accelerations, this Torque (subject torque) will be different from the torque measured at the motor shaft (torque sensor reading), which will be called “Shaft Torque” in this HRD. The difference will be the torque required to accelerate the moment of inertia of the human adapter and the part of the motor shaft between the adapter and the torque sensor (External shaft).

Note: On ground operations, Shaft and subject torque’s additionally differ due to the effect of gravity on the human adapter. For consistency of the ground and flight software, the above defined Torque (Subject Torque) shall not automatically compensate this influence of gravity. MARES profile editing and post-processing capabilities shall allow this gravity compensation for ground use.

3.1.2.1.2.1.2 Subject Position

Unless otherwise stated, in this HRD the term Position refers either to the angular or linear position of the moving human adapter, excluding the soft pads, and measured at a point representing the worst case. Equivalently with Velocity and Acceleration.

The absolute zero angular Position shall correspond with the opposite of the gravity vector in 1-g operations (vertical-up).

3.1.2.1.2.1.3 Concentric motion

A motion is considered concentric when the direction of subject torque (force) is the same as the direction of the motion.

3.1.2.1.2.1.4 Eccentric motion

A motion is considered eccentric when the direction of subject torque (force) is opposite to the direction of the motion.

3.1.2.1.2.1.5 Concentric/eccentric motion

This is a motion that allows the subject to change from concentric motion to eccentric motion, or vice versa, without a perceivable gap.

3.1.2.1.2.1.6 Measured data

These are all data generated within MARES, excluding Processed data:

- Scientific data: Shaft Torque/Force, Velocity, Position
- Hardware housekeeping,

- target signals (pre-programmed waves)
- etc.

3.1.2.1.2.1.7 Acquired data

These are all data acquired from external devices like PSC, PEMS, etc.:

- via general purpose analogue and discrete inputs,
- via general purpose serial line

3.1.2.1.2.1.8 Processed data

These are: the complete software status, and all data calculated by MARES according to programmable functions to be programmed by the experimenter, like:

- Parallel Processing
- Immediate Post-Processing
- software generated: Experiment/Profile/BMU step status and identification, Experiment variables, internal timers, general status, etc.
- Subject Torque

These terms correspond to MARES concepts defined in the next paragraphs and in MARES Payload Software Specification, MARES-SP-007.

3.1.2.1.2.2 MARES Basic Motion Unit (BMU)

3.1.2.1.2.2.1 BMU concept

A Basic Motion Unit shall be the lowest level of definition of any controlled motion. It shall consist of a start condition, a single algorithm with associated functions, and several end conditions.

BMU shall be defined by at least the following programmable elements:

> **Start conditions**. It shall be possible to start a basic motion unit by a programmable trigger condition, which shall be based on comparisons of any of the measured and acquired data, against parameters pre-set before BMU execution. Before this Start condition MARES shall remain in a Wait phase.

End conditions. It shall be possible to end a basic motion unit by two programmable end conditions, which shall be based on comparisons of the measured and acquired data, and time, against parameters pre-set before BMU execution. After ending a BMU, the control shall go to the next BMU in the profile.

Abort conditions. It shall be possible to abort a basic motion unit by a programmable abort condition, which shall be based on comparisons of the measured and acquired data, and time, against parameters pre-set before BMU execution. After aborting a BMU, the profile shall be stopped.

BMU type. This shall define the single motion algorithm to be performed by the motor. Chapters 3.1.2.1.2.2.2 through 3.1.2.1.2.2.16 identify the BMU types that shall be supported by MARES.

Display. It shall be possible to program which measured and acquired data are to be displayed to the subject, and the layout and characteristics of this display.

Archive. It shall be possible to program which measured and acquired data, and which time interval, are to be archived in the MARES mass storage.

Immediate post-processing. It shall be possible to program which measured and acquired data, and which rate and time interval, are to be temporally stored for immediate post-processing, and also which post-processing is performed with them. This processing shall at least cover signal delay and any processing covered by Labview. It shall be possible to use the results of this post-processing as acquisition data and to modify or replace the parameters of another profile.

Parallel processing. It shall be possible to program which measured and acquired data, and which rate and time interval, are to be processed in parallel to the execution of the BMU. This processing shall at least cover and cascade the basic arithmetic, comparison, Boolean, filter, signal delay, Peak detection and Mean functions. It shall be possible to use the results of this post-processing as acquisition data and as BMU end condition.

Time to trigger of external device. It shall be possible to program the time to trigger of an external device from the beginning of any Wait and BMU phase. Fix and random times shall be allowed. Up to two devices shall be independently supported.

Time to Mark. It shall be possible to program the time to a Mark from the beginning of any Wait and BMU phase. Mark shall be a 2-states binary parameter, part of the MARES Processed parameters. Fix and random times shall be allowed. Up to two Marks shall be independently supported.

Prompts. It shall be possible to program that during BMU execution, MARES displays to the subject stimulus instructions and prompts. Their format shall also be programmable.

Looping. It shall be possible to program loops of a single BMU and change its parameters sequentially on each loop, following a programmable table.

3.1.2.1.2.2.2 Isometric BMU

The isometric BMU is composed of two phases:

In the first phase, MARES shall bring the Subject Position to the programmable set position parameter of the BMU.

In the second phase, MARES shall maintain this position.

Both objectives shall be achieved irrespective of the Subject Torque or Force, if within limits.

3.1.2.1.2.2.3 Isokinetic BMU

The isokinetic BMU is composed of two phases:

In the first phase, MARES shall accelerate until Subject Velocity reaches the programmable set velocity parameter of the BMU.

In the second phase, MARES shall maintain this velocity.

Both objectives shall be achieved irrespective of the Subject Torque or Force, if within limits.

The following motions shall be supported:

- Concentric
- Concentric with compensation of human adapter inertia
- Concentric with eccentric acceleration
- Eccentric
- Concentric/eccentric

3.1.2.1.2.2.4 Isotonic BMU

The isotonic BMU is composed of two phases:

In the first phase, MARES shall increase Torque/Force until it reaches the programmable set torque/force parameter of the BMU.

In the second phase, MARES shall maintain this torque/force.

Both objectives shall be achieved irrespective of the Velocity, if within limits.

It shall be possible to select if this algorithm refers to Torque/Force, as defined, or alternatively to the Shaft Torque.

It shall be possible to increase or decrease the actual moving (moment of) inertia with a virtual (moment of) inertia simulated by the algorithm.

It shall be possible to emulate the behaviour of the commercial dynamometer CYBEX® 6000, when programmed in isotonic mode.

The following motions shall be supported:

- Concentric
- Eccentric
- Concentric/eccentric

3.1.2.1.2.2.5 Spring BMU

In the spring BMU, MARES shall maintain the function Torque/Force divided by Position equal to a programmable Spring coefficient parameter of the BMU.

In this mode, the subject should feel as if he was strapped to the end of a spring. In angular motion, the spring simulation corresponds to a circular spring.

It shall be possible to select if this algorithm refers to Torque/Force, as defined, or alternatively to the Shaft Torque.

It shall be possible to program the Spring coefficient:

- as a constant (Hooks constant),
- as a function of time,
- as a function of position.

The following motions shall be supported:

- Concentric/eccentric

3.1.2.1.2.2.6 Friction BMU

In the friction BMU, MARES shall maintain the function Torque/Force divided by Velocity equal to a programmable Friction coefficient parameter of the BMU.

In this mode, the subject should feel viscosity phenomena.

It shall be possible to select if this algorithm refers to Torque/Force, as defined, or alternatively to the Shaft Torque.

It shall be possible to program the Friction coefficient:

- as a constant,
- as a function of time,
- as a function of position.

The following motions shall be supported:

- Concentric/eccentric

3.1.2.1.2.2.7 Additional Moment of Inertia/Mass BMU

In the Additional Moment of Inertia/Mass BMU, MARES shall maintain the function Torque/Force divided by Acceleration equal to a programmable inertia coefficient parameter of the BMU. This implies that MARES shall be able to add or subtract a Jadd/Madd to the actual inertia seen by the subject (human adapter, motor shaft, etc.).

In this mode, the subject should feel as if he is strapped to an additional inertia/Mass.

It shall be possible to select if this algorithm refers to Torque/Force, as defined, or alternatively to the Shaft Torque.

It shall be possible to program the Jadd/Madd coefficients:

- as a constant,
- as a function of time,
- as a function of position.

The following motions shall be supported:

- Concentric/eccentric

3.1.2.1.2.2.8 Pseudo-gravitational BMU

In the Pseudo-gravitational BMU, MARES shall simulate the Torque/Force that a Mass would exert to the subject, being subjected to a gravity environment. The value of this mass, its position, and the gravity vector direction and intensity, shall be programmable.

It shall be possible to program the mass value:

- as a constant,

- as a function of time,
- as a function of position.
- as a multiplication of two independent functions, one time dependent and the other position dependent (f(t) * f(θ)).

The following motions shall be supported:

- Concentric/eccentric

3.1.2.1.2.2.9 Position control BMU

In the Position control BMU, MARES shall bring the Subject Position to follow the programmable set position parameter of the BMU, irrespective of the torque (force) applied by the subject.

It shall be possible to program the set position:

- as a constant,
- as a function of time.

The following motions shall be supported:

- Concentric/eccentric

3.1.2.1.2.2.10 Velocity control BMU

In the Velocity control BMU, MARES shall bring the Subject Velocity to follow the programmable set velocity parameter of the BMU, irrespective of the torque (force) applied by the subject.

It shall be possible to program the set velocity:

- as a constant,
- as a function of time.

The following motions shall be supported:

- Concentric/eccentric

3.1.2.1.2.2.11 Torque/Force control BMU

In the Torque/Force control BMU, MARES shall bring the Subject Torque/Force to follow the programmable set torque/force parameter of the BMU, irrespective of the Velocity.

It shall be possible to select if this algorithm refers to Torque/Force, as defined, or alternatively to the Shaft Torque.

It shall be possible to program the set torque/force:

- as a constant,
- as a function of time,
- as a function of position.
- as a multiplication of two independent functions, one time dependent and the other position dependent ($f(t) * f(\theta)$).

The following motions shall be supported:

- Concentric
- Eccentric
- Concentric/eccentric

3.1.2.1.2.2.12 Power control BMU

In the Power control BMU, MARES shall maintain the function Torque/Force multiplied by Velocity equal to a programmable Power parameter of the BMU.

This mode can be compared to the functionality of an ergometer power controlled.

It shall be possible to program the Power parameter:

- as a constant,
- as a function of time.

The following motions shall be supported:

- Concentric

3.1.2.1.2.2.13 Physical elements BMU

In the Physical elements BMU, MARES shall simulate the Torque/Force that the Spring, Inertia and Friction elements placed in parallel (same velocity for all of them) would generate.

It shall be possible to select if this algorithm refers to Torque/Force, as defined, or alternatively to the Shaft Torque.

It shall be possible to program the Spring, Inertia and Friction coefficients:

- as constants.

The following motions shall be supported:

- Concentric/eccentric

3.1.2.1.2.2.14 Extended torque/force control BMU

In the Extended torque/force control BMU, MARES shall simulate the Torque/Force that the Spring, Inertia and Friction elements placed in parallel (same velocity for all of them) would generate, with the addition of a programmable set torque/force.

It shall be possible to select if this algorithm refers to Torque/Force, as defined, or alternatively to the Shaft Torque.

The following shall be possible:

- Torque/Force as a multiplication of two independent functions, one time dependent and the other position dependent ($f(t) * f(\theta)$), being the coefficients of the (Spring, Inertia and Friction) constant.
- The physical elements as a function of a single product ($f(t) * f(\theta)$), being the Torque/Force constant.

The following motions shall be supported:

- Concentric/eccentric

3.1.2.1.2.2.15 Quick release BMU

In the Quick release BMU, MARES shall simulate the sudden release of the moving limb of the subject, when he/she is performing an isometric manoeuvre.

It shall be possible to select if this algorithm “releases” before or after the human adapter, this means that the sudden decrease of torque refers to Torque, as defined, or alternatively to the Shaft Torque.

Alternatively this functionality could also be covered by a dedicated profile instead than by a specific BMU.

The following motions shall be supported:

- Concentric

3.1.2.1.2.3 MARES Profiles

It shall be possible to form a Profile as a branching and looping sequence of Basic Motion Units, which will be performed by the subject while being continuously strapped to the MARES human adapter.

The basic structure of a Profile shall be as shown in the Figure 3.1.2.1.2.3 - Basic profile structure.

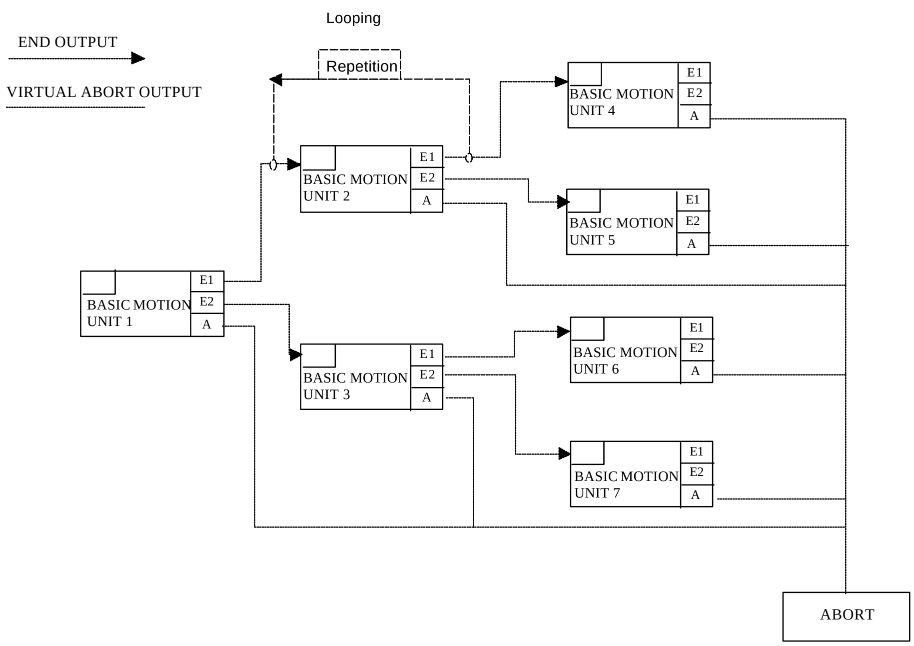


Figure 3.1.2.1.2.3 - Basic profile structure

The branching capability within a MARES Profile shall be implemented by the interconnection of Start and End elements of the different BMU’s. There shall be less than 8ms between the occurrence of the End condition and the start of the next BMU. The algorithm of the ended BMU shall be extended during this elapsed time.

The looping function of several BMU's shall allow changing their parameters sequentially on each loop, following a programmable table.

The programming capabilities for creating this sequence and looping of BMUs shall naturally cover all the tests contained in MAR-701-ESA/AK, Science and Operations Evaluation Plan (SOEP).

3.1.2.1.2.3.1 Standard profiles

MARES shall include Standard Profiles defined as pre-programmed Profiles that shall provide a functionality equivalent to existing commercial dynamometers (CYBEX 6000®).

The provided Standard Profiles shall at least be the following:

- Isometric profile
- Isokinetic profile
    - Concentric (flexion/extension)
    - Eccentric (flexion/extension)
    - Concentric/Eccentric (flexion/extension)
    - Eccentric/Concentric (flexion/extension)
- Isotonic profile
    - Concentric (flexion/extension)
    - Eccentric (flexion/extension)
    - Concentric/Eccentric
- CPM (continuous passive motion)

    Defined as a set of isokinetic concentric or eccentric standard profiles that normally are executed during a long period of time (several minutes). Between sets, there is a pause time and the CPM halt condition is defined by torque limit or when the subject presses the halt button.

The basic parameters of these profiles shall still be programmable.

3.1.2.1.2.3.2 Custom profile

Custom Profile is a profile that allows full programmability of its elements. It shall be possible to create, edit and execute Custom Profiles with MARES.

3.1.2.1.2.4 MARES Experiments

It shall be possible to form an Experiment as a branching and looping sequence of the following basic programmable elements:

- description of the experiment,
- branching and looping elements,
- parameter setting elements
- Crew Procedures. Covering among others:
    - how to set up the mechanical adapters proposing settings for the restraints according to the Crew Member Database,
    - how to ingress in MARES,
    - experiment instructions, etc.,
- Crew prompting. Covering among others:
    - status reporting,
    - warnings,
    - request for operator inputs,
    - impact messages synchronised with the profile phases, etc.,
- the activation of MARES Profiles. It shall be possible to automatically change their parameters,
- setting-up and commanding of external devices, i.e.: PEMS,
- communication with HRF and ISS,
- display. It shall be possible to program which measured, acquired and processed data are to be processed and displayed to the subject, and the layout and characteristics of this display.
- data archive.

The automatic change of the Profile and BMU’s parameters shall be implemented, prior to the Profile activation, from the following sources:

- from manual input from the operator,
- from measured and acquired data,

- from results from the Immediate Post-processing of a previous profile,
- sequentially on each experiment loop, following a programmable table.

The interaction MARES Profile and MARES Experiment is shown in Figure 3.1.2.1.2.4 - MARES Experiment concept.

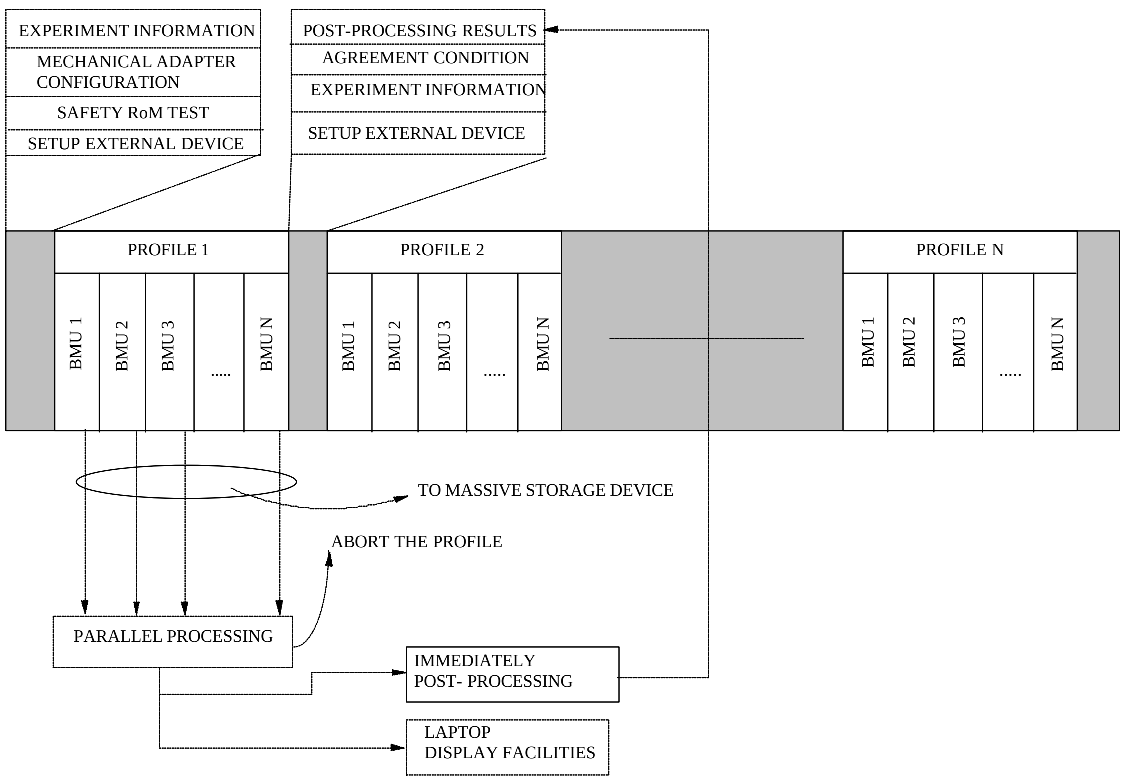


Figure 3.1.2.1.2.4 - MARES Experiment concept

The branching elements shall be based on either operator interaction, or on time, or on comparisons of the measured, acquired and processed data, against fix values pre-set in the experiment.

In an Experiment, it shall be possible to generate, set (either to a fixed value or to an input from the operator), and operate with, internal experiment specific parameters or variables. They shall be part of the Measured data.

The looping within an Experiment shall allow changing the BMU’s parameters sequentially on each loop, following a programmable table.

It shall be possible to program each Experiment step (element) either to be executed immediately or after operator confirmation.

The programming capabilities for creating this sequence and looping of Experiment elements shall naturally cover all the tests contained in MAR-701-ESA/AK, Science and Operations Evaluation Plan (SOEP).

3.1.2.1.3 Human Restraint System

The MARES Human Restraint System (HRS) includes the Human Adapters and the Chair. For ground operation, the HRS may be supplemented with GSE.

The MARES Human Restraint System shall be designed to meet the following functional requirements:

3.1.2.1.3.1 Scientific requirements

3.1.2.1.3.1.1 Muscular group isolation

The HRS shall allow good isolation of the muscular groups under study (primary groups) for a particular movement. These muscular groups should be the only groups involved in the performance of the movement.

No other muscular group, different from the muscular group of the movement, shall collaborate in the performance of the movement under study. Only isometric activation of these other muscular groups shall be allowed.

No other muscle groups shall be needed to immobilise the main body.

It shall be possible for the experimenter to optionally select that the muscle groups holding the head are exempt from complying with this previous requirement.

3.1.2.1.3.1.2 Impairment

The HRS shall allow performing the natural movement under study.

The primary muscular group shall not be pressed by any restraint.

3.1.2.1.3.1.3 Primary joint Position

MARES Position accuracy is defined in 3.1.2.2.2. This accuracy refers to the moving human adapter, excluding the soft pads, and measured at the worst case point. The actual accuracy in joint position, as well as the comfort, will both depend on the flexibility of the pads, although influencing in opposite directions.

MARES HRS design shall represent the best compromise between the Comfort and joint position Accuracy requirements.

3.1.2.1.3.1.4 Joint alignment

MARES shall allow the initial alignment of the primary joint axis with the motor shaft within :

- 2 mm, for Ankle, Elbow, Wrist (all) movements
- 3 mm, for Knee movements
- 5 mm, for Shoulder, Hip, Trunk movements

In those movements where there is not a single joint axis, an equivalent joint centre shall be chosen, such as to allow an as circular as possible trajectory of any distal point, for the whole ROM.

3.1.2.1.3.1.5 Joint alignment stability

The actual alignment of the joint axis to the motor shaft, during the performance of a movement, shall not deviate more than the following Alignment Error, from the initial alignment position defined above:

- 15 mm, for Ankle movements
- 20 mm, for Elbow, Wrist (all) movements
- 30 mm, for Knee, Hip, Trunk movements
- 40 mm, for Shoulder movements

It shall be a design goal to reduce these figures by 40%.

3.1.2.1.3.1.6 Body position reproducibility

For any given movement, the position of the joint axis shall be reproducible between two different runs of the same experiment. The error in the joint axis position between two different runs shall be lower than the values defined in 3.1.2.1.3.1.3.

3.1.2.1.3.1.7 Electrodes compatibility

The HRS shall be compatible with the use of ECG or EMG electrodes on the primary and secondary muscle groups, during the experiment. The applicable configuration of electrodes is defined in MAR-718-ESA/AK, dated 01 December 1997.

3.1.2.1.3.1.8 Anthropometric range covered

The design shall cover the Anthropometric dimensions of all the population ranging between 1,05 times the anthropometric dimensions of the American male 95 percentile and the anthropometric dimensions of the Japanese female 5 percentile as defined in Flight Crew SSP 50005 revision B.

If a particular dimension is not found in this document, Anthropometric source book. Volume II: A Handbook of Anthropometric Data (NASA reference publication 1024), July 1978, shall be used as a second source.

If a particular dimension is not found in any of these two documents, particular scientist data bases can be used if the data base includes population that can be considered representative of the expected Astronaut population.

Only for reference, some of the dimensions extracted from these documents are presented in Table 3.1.2.1.3.1.8 - Anthropometric range covered.

Movement	Anthropometric dimension	Max and min dimensions (mm)	Source
Elbow flexion/extension	Forearm-hand length	545 - 373	SSP 50005B
Ankle dorsi/plantar flexion	Foot length	308 - 213	SSP 50005B
Knee flexion/extension	Tibiale Height	571 - 359	NASA ref. 1024
Hip flexion/extension	Trochanteric Height	1080 - 710	SSP 50005B
Wrist flexion/extension	Hand Length	216 - 158	SSP 50005B
Wrist abduction/adduction	Hand Length	216 - 158	SSP 50005B
Wrist pronation/supination	Hand Breadth	101 - 69	SSP 50005B
Trunk flexion/extension	Head-dorsal and lumbar section of trunk	554 - 730	NASA ref. 1024
Shoulder flexion/extension	Arm-hand	882 - 652	NASA ref. 1024
Both arms flexion/extension	Arm-hand reach	926 - 652	SSP 50005B
Single leg flexion/extension	Trochanteric Height	1080 - 710	SSP 50005B

Table 3.1.2.1.3.1.8 - Anthropometric range covered

3.1.2.1.3.2 Comfort requirements

3.1.2.1.3.2.1 General requirement

Subject discomfort must not affect the normal performance of an experiment in MARES.

3.1.2.1.3.2.2 Pain

No points of Pain due to the HRS shall be found before, during and after the performance of any movement (including maximal activation). The maximum duration of an experiment to be considered for this requirement is 30 minutes.

3.1.2.1.3.2.3 Impairment

The HRS shall apply a pressure to the different parts of the body that shall not produce any physiological disorder at any region of the body (e.g. pressure over nerves or occlusion of main blood vessels).

3.1.2.1.3.2.4 Immobilisation

The HRS shall prevent uncomfortable movements of the rest of the subject's body by involuntary contractions both, in microgravity and in 1g conditions.

3.1.2.1.3.2.5 Orthostatic intolerance

The movements in MARES shall be carried out in a position compatible with post-flight data collection position such to avoid physiological problems due to the lack of orthostatic tolerance in post flight measurements. This means that the position of the subject must be close to a supine position whenever possible.

This requirement does not apply to Wrist pronation/supination and Trunk flexion/extension movements.

In Knee flexion/extension movement, the fixed trunk inclination shall not deviate more than 30° from the supine position.

3.1.2.1.3.2.6 Sharp edges

Pads and bumpers shall be free of sharp edges**.**

3.1.2.1.3.2.7 Pads Material

The material in contact with the skin shall represent a good compromise taking into account the following requirements:

- **Abrasion.** This material shall be not abrasive to avoid damage of the skin.
- **Friction.** This material shall avoid sliding of the segment.
- **Sweat.** This material shall allow for skin ventilation, and shall have high thermal capacity and low thermal conductance, to minimise accumulation of sweat in contact with the skin.
- **Cleanliness.** This material shall be easy to clean (high chemical inertia, low water absorption, and smooth texture).

3.1.2.1.3.2.8 Pads shape memory

The pads touching the subject skin shall be firm shock absorbents, shall adapt to the physiological shape of the subject restrained parts and shall not suffer from permanent deformation regarding this shape adaptation.

3.1.2.1.3.3 Safety requirements

3.1.2.1.3.3.1 General requirement

The human adapters design shall prevent any unsafe condition when operating MARES according to the instructions in the MARES User Manual, even in the event of unintentional subject or operator errors.

3.1.2.1.3.3.2 Structural failure

The human adapter design shall prevent any crew or Station safety hazard derived from structural failures.

3.1.2.1.3.3.3 Emergency egress

The test subject shall be able to egress MARES from any restrained position and exercise, in less than 30 seconds without the help of a second crewmember.

3.1.2.1.3.3.4 Mechanisms

All the HRS mechanisms shall allow quick release with a simple movement.

3.1.2.1.3.3.5 Electrical isolation

The subject restraints shall electrically isolate the subject body with respect to ISS ground to not disturb physiologic measurements, nor to create any safety hazard.

3.1.2.1.3.4 Operational requirements

3.1.2.1.3.4.1 Single person use

The HRS design shall minimise the need for a second person to support the test subject for the adjustment of the human adapters and to restraint himself to MARES.

3.1.2.1.3.4.2 Identification of adapters

MARES shall be able to automatically identify to which movement group the installed human adapters correspond.

3.1.2.1.3.4.3 Modular design

The HRS shall be designed following a modular design approach that is maximising the number of movements covered by each part.

The attachment features of the MARES Main Box for the HRS shall foresee a wider range of adapters than strictly the elements required by the requirements in this HRD.

3.1.2.1.3.5 Requirements priorities

Whenever technically possible all requirements contained in 3.1.2.1.3.1 through 3.1.2.1.3.4 shall be met.

In case of conflict between them, and if the contractor can prove that there is no possible solution able to resolve the conflict, the Contractor may prioritise the requirements according to the following list (1=highest priority):

1.- Safety requirements
2.- Comfort and Scientific req.
3.- Operational req.

In case of conflict between Comfort and Scientific requirements, and if the Contractor can prove that there is no technical solution able to resolve the conflict, the Contractor shall present several solutions to the Agency and seek resolution of the conflict. The Agency will consult its scientific (Facility Science Team) and operations (Crew representatives, Human Factors) advisers for a response.

3.1.2.1.4 Laptop Computer

The flight laptop computer provided by HRF will at least provide the following functionality and characteristics:

- To be portable.
- To include a multi-use bracket assembly.
- To be equivalent to a “PC compatible” with the following minimum characteristics:

PROCESSOR	Pentium 166 MHz.
RAM MEMORY	64 Mbytes
HARD DISK	Permanently 1 MB for the start-up program Temporally 50 MB during operation
SCREEN	SVGA compatible 1024 x 768
KEYBOARD	Standard
POINTING DEVICE	Standard
COMMUNICATION	Ethernet 10-base-T (card)
CD-ROM DRIVER	Required
OPERATING SYSTEM	Windows NT 4, SP4 or later, compatible
Including:	TPC/IP protocol NFS client (ViewNow InterDrive Client, v7.0, from Netmanage [former "FTP Software"]) properly installed and configured. 32 bits ODBC (Open Database Connectivity) Driver Manager and Microsoft Access DBMS (Data Base Management System) driver. (*)
Installed software	WEB BROWSER : Internet Explorer 4.0 or any other with at least the same functionality. MICROSOFT OFFICE: With WORD, EXCEL and ACCESS elements installed.

* This is already installed in case of Microsoft Office installed with the Microsoft Access element

The NFS client configuration shall be identified by the contractor and documented following the applicable templates defined in the HRF Software Development Plan LS-71020, section A4.0.

In case that the installation of the MARES SW implies the addition of DLLs in the Windows directories, these DLLs shall be documented following the applicable templates defined in the HRF Software Development Plan LS-71020, section A4.0.

In case that the installation or operation of the MARES SW implies to modify the Windows registers or any other part of the OS environment, these modifications shall be documented following the applicable templates defined in the HRF Software Development Plan LS-71020, section A4.0.

3.1.2.1.5 Launch Structure Assembly

The Launch Structure Assembly (LSA) will be provided by NASA / HRF.

The LSA will allow the launch of MARES in the MPLM.

The LSA will allow the accommodation of structurally mounted MARES elements, with masses and envelopes as defined in 3.1.4 of this HRD.

The LSA will allow the accommodation of the stowed MARES elements in containers, with masses and envelopes as defined in 3.1.4 of this HRD.

The structurally mounted MARES elements will be bolted to a flat surface of the LSA.

The LSA flat surface will have through holes according to a hole pattern defined in the MARES Interface Specification.

The launch acceleration vector will be parallel to this LSA flat surface.

The LSA with and without MARES shall have a first resonance frequency higher than 35 Hz.

The MARES launch structure assembly shall show positive margins according to SSP 52005 document for the launch loads assuming a MARES launch mass as defined in 3.1.4.1 of this HRD.

The LSA will comply with the MARES interface requirements defined in 3.1.5.1 of this HRD.

3.1.2.1.6 MARES operation

During launch and landing, the MARES elements will either be **mounted** on the Launch Structure Assembly (LSA) or **stowed** in LSA launch containers. During on-orbit operations, the MARES will be **deployed** in the aisle. When not used on-orbit MARES will be **stowed**.

3.1.2.1.6.1 Human factors requirements

MARES shall be designed such as to simplify its operation and to minimise the crew time required.

Mechanisms requiring certain strength for their activation shall foresee their operation in 0g.

MARES’ design shall foresee that the subject will normally be the operator as well. For example, because of this requirement, the design of the support of the HRF PCS shall take into account the limited mobility of the subject already strapped for the performance of a certain movement. If the multi-use bracket assembly that interfaces with the HRF PCS does not provide this functionality, MARES shall include its own bracket.

For the performance of an existing MARES experiment, only few training sessions and basic knowledge on the use of Windows NT applications, shall be required from the subject and operator.

MARES shall provide easy ways to recover from unintentional operational mistakes.

Unintentional operational mistakes shall not lead to hazardous situations.

3.1.2.1.6.2 Compatibility requirements

3.1.2.1.6.2.1 Hatches compatibility

MARES’ elements shall have an envelope compatible with ISS, MPLM and Shuttle hatches and operations within ISS.

3.1.2.1.6.2.2 Standalone operation

It shall be possible to operate MARES without data connection to HRF for 1 hour, and without loosing any data. In this autonomous mode, MARES shall store the generated data, for later transfer to HRF using either Ethernet link or removable storage media.

3.1.2.1.6.2.3 Maintenance

MARES’ design shall be modular to ease its maintenance.

3.1.2.1.6.3 Operational times

3.1.2.1.6.3.1 Initial assembly

MARES' initial assembly from the launch to the **deployed** configurations, and its related testing, shall all take less than 3 man-hours.

3.1.2.1.6.3.2 On-orbit assembly

MARES' assembly from the **stowed** to the **deployed** configurations, up to the point when MARES is ready to select and start an experiment, shall take less than 10 man-minutes.

This time shall not include the set-up of the human adapters, which is part of the MARES experiment.

3.1.2.1.6.3.3 Experiment set-up

MARES set-up, from the **deployed** configuration ready to select and start a MARES experiment, up to the experiment step instructing the subject to ingress and strap him/herself to MARES, shall take less than 10 man-minutes.

These initial steps of the experiment shall at least cover:

- software loading, including the experiment self,
- setting and installing the human adapters according to the stored personal settings of the subject.

3.1.2.1.6.3.4 Subject self-strapping

After MARES set-up, it shall be possible to get the subject completely strapped to MARES, and ready to perform any of the covered movements, in less than 10 man-minutes.

The need for a second person to help on this procedure shall be minimised.

3.1.2.2 Technical specifications

Unless otherwise mentioned, these technical specifications will use the terms in 3.1.2.1.2.1 of this HRD, with the meanings defined there.

3.1.2.2.1 Absolute maximum ratings

3.1.2.2.1.1 Torque limits

MARES shall be able to apply both, a Subject and a Shaft torque of up to ±450 Nm for up to 120 seconds per hour, an average of up to ±160 Nm continuously, and a Shaft torque of up to ±900 Nm in peaks of up to 200 ms, which will occur not more often than once a five seconds, and not totalling more than 500 pulses per hour.

MARES shall be able to support Shaft torque pulses of longer duration's with the same rate of occurrence, provided their amplitude times the duration does not exceed 180 Nm s.

3.1.2.2.1.2 Force limits

MARES shall be able to apply a force between the subject and the linear human adapter of up to ±240 N continuously.

3.1.2.2.1.3 Angular velocity limits

MARES shall be able to reach a maximum angular velocity as defined in the following table.

Movement	Max eccentric angular speed (rad/s)	Max concentric angular speed (rad/s)
Ankle	±6	±9
Elbow	±6	±9
Shoulder	±5.5	±5.5
Wrist	±6	±9
Knee	±6	±6
Hip	±3	±3
Trunk	±3	±3

Table 3.1.2.2.1.3 - Maximum angular velocity

MARES shall be able to reach a maximum linear velocity of ±0.5 meter/s both, in concentric and in eccentric.

3.1.2.2.1.4 Angular position limits

MARES shall be able to provide any joint angle positions of the entire circle (0° to 360°). It shall be possible to turn the MARES shaft an indefinite number of turns.

3.1.2.2.1.5 Linear position limits

MARES shall be able to provide any linear position between 0 and 1 meter.

3.1.2.2.1.6 Power limits

MARES shall be able to provide a continuous power load to the subject, that is the multiplication of actual Torque by the actual Velocity, corresponding to any point under the “Motor torque” line in Figure 3.1.2.2.3.1.2 during up to two minutes per hour.

MARES shall be able to provide a continuous power load to the motor shaft, that is the multiplication of actual Shaft torque by the actual Velocity, corresponding to any point under the “Motor torque” line in Figure 3.1.2.2.3.1.2 during up to two minutes per hour.

MARES shall be able to provide peaks of this power load to the motor shaft corresponding to any point under the “Peak torque” line in Figure 3.1.2.2.3.1.2. It shall be possible to provide peaks with the same duration and occurrence characteristics as the Torque pulses defined in the Torque limits paragraph.

3.1.2.2.2 Measurement capabilities

In the following sections, the measurement accuracy is defined as the error between the actual value of the parameter and the data stowed or sent to HRF or GSE computer.

MARES shall be able to measure the following parameters with the following characteristics:

3.1.2.2.2.1 Torque measurement

MARES shall provide for measuring a Shaft Torque at the sensor on the motor shaft of between 0 Nm and up to ±450 Nm (approx. 300 ft-lb), with an accuracy of better than ±[0.3 Nm + 0.5 % of |the measured value|].

For Shaft Torque’s between ±450 Nm and up to ±900 Nm (approx. 600 ft-lb), the accuracy shall be better than ± 1 % (± 9 Nm) of the end of scale.

The analogue bandwidth (-3 dB) of the Shaft Torque transmitted parameter shall at least be from 0 Hz to 500 Hz.

Note: In this HRD, when an "analogue bandwidth (-3dB)" is given, this means that between the indicated frequencies, the amplitude of the parameter will not be attenuated more than 3 dB. Outside the indicated frequency range the attenuation shall at least be 12 dB/octave. This definition is independent of the actual filtering method, either analogue or digital.

In transitions, the Shaft Torque at the torque sensor will differ from the processed subject Torque in a magnitude equal to the Acceleration times the moment of inertia of the human adapter and outer motor shaft. MARES shall automatically calculate this subject Torque.

MARES shall provide for measuring a Torque between the subject and the human adapter of between 0 Nm and up to ±450 Nm (approx. 300 ft-lb), with an accuracy of better than

- ±[1 Nm + 2 % of |the measured value|], for Ankle and Wrist.
- ±[3 Nm + 2 % of |the measured value|], for Elbow.
- ±[8 Nm + 2 % of |the measured value|], for Shoulder and Knee.
- ±[20 Nm + 2 % of |the measured value|], for Hip and Trunk.

The analogue bandwidth (-3 dB) of the subject Torque parameter shall at least be from 0 Hz to 200 Hz.

3.1.2.2.2.2 Force measurement

MARES shall provide for measuring a force between the subject and the linear human adapter of between:

- 0 and ± 240 N in the movement axis
- 0 and ± 80 N in the other two axes

MARES shall provide for measuring a torque between the subject and the linear human adapter around the handgrip axis of between:

- 0 and ± 4 Nm.

MARES shall provide independent measure on each left and right limb and on each left and right end of the handgrip or foot plate.

The accuracy of the measured parameter shall better than:

- ± [0.125 N + 1% of |the forces applied in the other axes|] for the forces.
- ± 0.002 Nm for the torque.

The analogue bandwidth (-3 dB) of the force parameter shall at least be from 0 Hz to 500 Hz.

3.1.2.2.2.3 Angular velocity measurement

MARES shall provide for measuring a joint angular velocity of between 0 and ±515°/s (approx. 9 rad/s), with at least the following accuracy for continuous torque's:

- ± [0.2 °/s + 0.5% of |the measured data|]

For transients on the subject torque, the transient additional error shall be less than ±2.5°/s times the slope of the torque change in Nm/ms.

The analogue bandwidth (-3 dB) of the angular velocity parameter shall at least be from 0 Hz to 200 Hz.

3.1.2.2.2.4 Linear velocity measurement

MARES shall provide for measuring a linear velocity of between 0 and ±0.5 m/s, with at least the following accuracy for continuous force's:

- ± [1 mm/s + 0.1 % of |the measured value|]

For transients on the subject force, the transient additional error shall be less than ±30 mm/s times the slope of the force change in N/ms.

The analogue bandwidth (-3 dB) of the linear velocity parameter shall at least be from 0 Hz to 200 Hz.

3.1.2.2.2.5 Position measurement

MARES shall provide for measuring a joint angle between 0° and 360°, with an accuracy of better than ± [Position Accuracy] as shown in the Figure 3.1.2.2.2.5.

MARES shall provide for measuring a linear position between 0m and 1m, with an accuracy of better than ± [Position Accuracy] as shown in the following figure.

	ankle	elbow	shoulder	wrist f/e	wrist p/s	wrist r/u	knee	hip	trunk	linear
Accuracy as % of ROM @ 50% torque/force	1.00	0.75	0.25	0.50	0.50	1.00	1.25	1.00	2.00	0.75

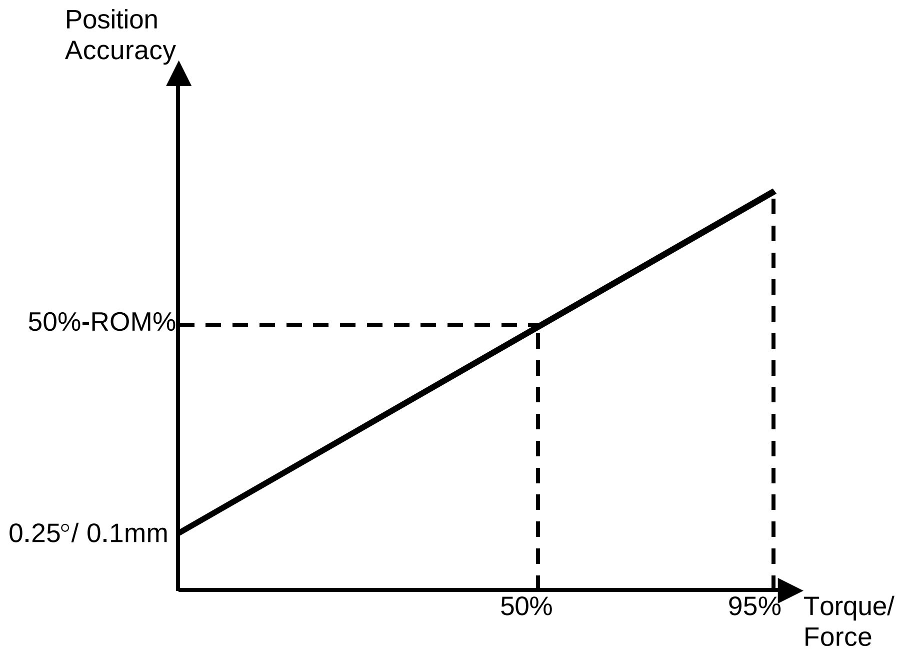


Figure 3.1.2.2.2.5 - Position Accuracy

ROM is defined in Table 3.1.2.1.1.3 of the HRD.

The 95% percentile maximum torque’s are defined in Table 3.1.2.2.3.1.4 of the HRD (except for the trunk = 450 Nm).

The 50% percentile maximum torque’s are defined as 60% of the 95% percentile maximum torque’s.

The 50% and 95% percentile maximum forces are 250 N.

The table below summarises these figures.

	ankle	elbow	shoulder	wrist f/e	wrist p/s	wrist r/u	knee	hip	trunk	linear
95% Max. torque / force (Nm / N)	275	165	190	30	30	30	450	450	450	250 (N)
50% Max. torque / force (Nm / N)	165	99	114	18	18	18	270	270	270	250 (N)

The analogue bandwidth (-3 dB) of the linear position parameter shall at least be from 0 Hz to 200 Hz.

3.1.2.2.2.6 Deleted

3.1.2.2.3 Modes performance

MARES shall be able to set one of the scientific parameters: either the Torque/Force, the Shaft torque, the Velocity, the Position, or a fix relation between them, to follow a programmable profile as a function of time, in accordance with the MARES Profile and BMU capabilities defined in 3.1.2.1.2 of this HRD.

MARES shall be able to set this scientific parameter, BMU dependent (see 3.1.2.1.2.2 of this HRD), within the ranges, dynamic responses and accuracy's defined in the following sections 3.1.2.2.3.x.

3.1.2.2.3.1 Common technical spec.

For all BMU modes, the following common requirements apply:

3.1.2.2.3.1.1 Range of subject Position

The range of angular and linear Position, in the nominal subject position defined in 3.1.2.2.4.2 (rest of the joints), for each of the supported movements listed in 3.1.2.1.1.3, shall at least cover the ROMs defined in 3.1.2.1.1.3 of this HRD.

All BMU modes having the Position as input parameter shall be able to work properly for Position signals having frequency components in a 3dB analogue bandwidth of up to 200 Hz.

To be able to adapt to future movements, the BMU modes shall cover unlimited turns of angular Position.

3.1.2.2.3.1.2 Range of Torque and Velocity

When the target torque/velocity of the BMU algorithm will continuously be within the area situated below the curve “Motor Torque” (lowest continuous line in graph), as presented in the Figure 3.1.2.2.3.1.2 - MARES torque velocity performance graph, MARES shall be able to control the actual torque/velocity within the accuracy's defined in the respective Steady State Accuracy paragraphs of each BMU. This applies to both, the Subject and the Shaft torque's. This defines the Continuous Limit of subject Torque.

When the target Shaft torque/velocity of the BMU algorithm will be within the area situated below the curve “Peak Torque” (top continuous line in graph), as presented in the Figure 3.1.2.2.3.1.2 - MARES torque velocity performance graph, and in pulses as defined in the

Torque limits paragraph, MARES shall be able to control the actual Shaft torque/velocity within the accuracy's defined in the respective Steady State Accuracy paragraphs of each BMU.

Note: The setting capabilities defined for each BMU may lead to targets outside the areas defined in the two previous paragraphs. In this case the accuracy figures are not applicable.

In the same figure, the maximal torque/velocity values reported in scientific publications, performed by healthy subjects, are showed for reference only.

All BMU modes having the Torque and Velocity as input parameters shall be able to work properly for Torque and Velocity signals having frequency components in a 3dB analogue bandwidth of up to 200 Hz.

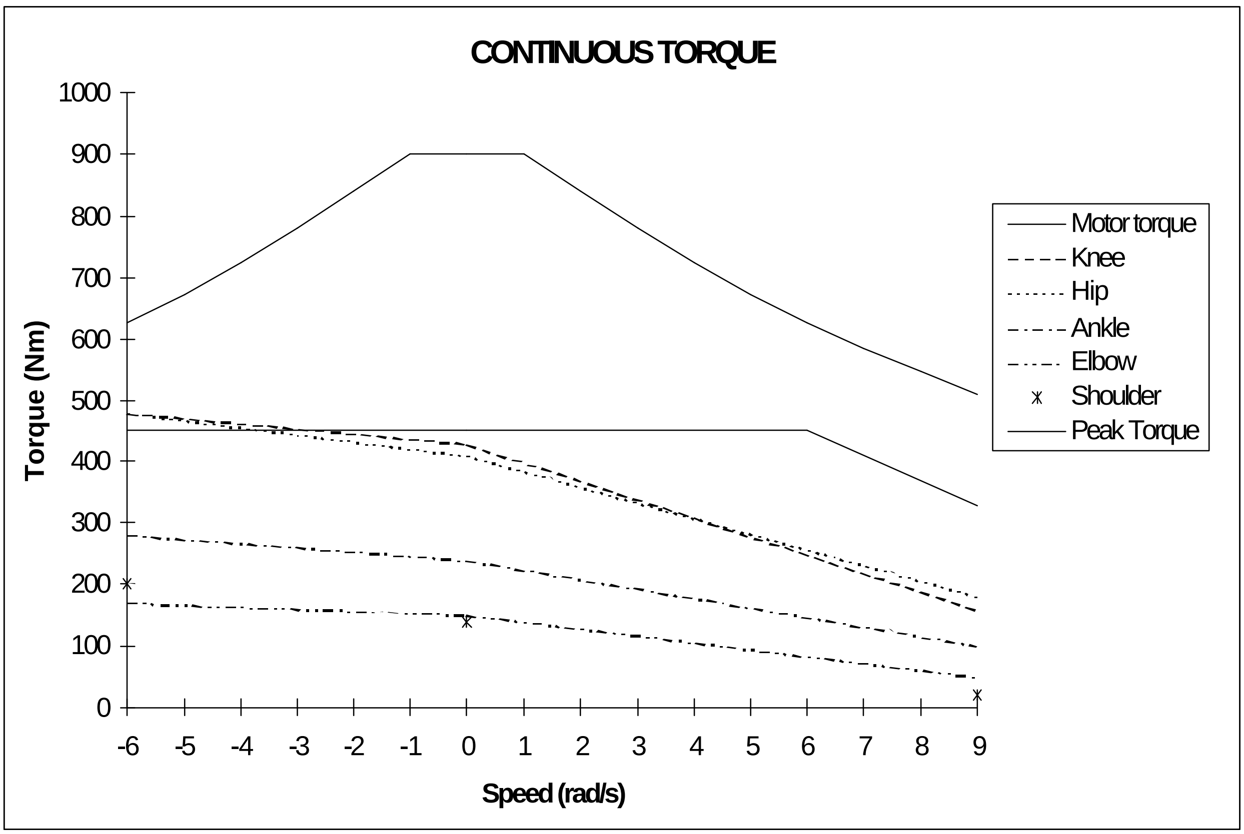


Figure 3.1.2.2.3.1.2 - MARES torque velocity performance graph

3.1.2.2.3.1.3 Range of Force and Velocity

When the target Force/velocity of the BMU algorithm will continuously be within the area situated below 250 N and ±0.5 m/s, MARES shall be able to control the actual

Force/velocity within the accuracy's defined in the respective Steady State Accuracy paragraphs of each BMU. This defines the Continuous Limit of subject Force.

Note: The setting capabilities defined for each BMU may lead to targets outside the areas defined in the previous paragraph. In this case the accuracy figures are not applicable.

All BMU modes having the Force and Velocity as input live parameters (not the target wave) to the algorithm, shall be able to work properly both: for Force and Velocity signals having frequency components in a 3dB analogue bandwidth of up to 200 Hz, and for accelerations of up to 40 cm/s^2.

3.1.2.2.3.1.4 Angular acceleration

MARES shall be able to accelerate, that is to change velocity, in times no longer than the figures presented in the Table 3.1.2.2.3.1.4 - Acceleration times, and in the Figure 3.1.2.2.3.1.4 - MARES ramp times calculation graph.

In this table the following terms are used:

Movement: with the exception of the Trunk (that MARES shall only cover sub-maximally to be able to comply with the MARES Mass budget), all angular movements are listed in this column, covering both cases, the 95% and the 5% percentile subject.

Eccentric torque: the given acceleration times shall be met against an opposing subject Torque no higher than the values listed in this column.

Limb Moment of Inertia (MoI): the given acceleration times shall be met with a subject's limb attached to the human adapter, having a moment of inertia not higher than the values listed in this column, extracted from bibliography. The figures are given in Kg m^2.

Human adapter Moment of Inertia (MoI): the given acceleration times shall be met with a human adapter attached to the motor shaft, having a moment of inertia not higher than the values listed in this column. The figures are given in Kg m^2. Section 3.1.2.2.4.3 of this HRD limits the MoI of these human adapters to the 95% percentile figures assumed here.

Velocity Ramp time: this acceleration time is defined as the time that the Velocity parameter takes to go from the first cross of the 5% of the target step, until the first cross of the target value. In the Table 3.1.2.2.3.1.4 - Acceleration times, the target velocity is the maximum in eccentric, defined in Table 3.1.2.2.1.3 - Maximum angular velocity. The Figure 3.1.2.2.3.1.4 - MARES ramp times calculation graph, defines the Ramp time for any target Velocity. The cases where the time figure is limited by safety limits and not by motor power limitations, are indicated with (*). In cases where the Ramp time for maximum angular velocity becomes very large, additionally the 2 rad/s Ramp time is given.

Velocity Stabilisation time: this acceleration time is defined as the time that the Velocity parameter takes to go from the first cross of the target value, until the Velocity goes into the Steady State, that is when the Velocity stays within the Steady State Accuracy margin specified in the following sections 3.1.2.2.3.x, for each Velocity/BMU mode.

Velocity Total Settle time: this acceleration time is simply the addition of the Ramp time and the Stabilisation time.

Movement	**Eccentric torque (Nm)**	**Limb MoI**	**Human adapter MoI**	**Ramp Time (ms)**	**Stabilisation Time (ms)**	**Total Settle time (ms)**
Ankle (95%)	275	0.021	0.25	10(*)	20	30
Ankle (5%)	110	0.006	0.25	10(*)	20	30
Elbow (95%)	165	0.14	0.72	15(*)	11	26
Elbow (5%)	66	0.07	0.72	15(*)	11	26
Shoulder (95%	190	0.95	3.2	40 @ 5.5 rad/s	10	50 @ 5.5 rad/s
Shoulder (5%)	76	0.37	2.1	21 @ 5.5 rad/s	8	29 @ 5.5 rad/s
Wrist (95%)	30	0.0038	0.30	10(*)	20	30
Wrist (5%)	12	0.0021	0.30	10(*)	20	30
Knee (95%)	450	0.53	0.71	35 @ *6 rad/s*	13 @ *6 rad/s*	48 @ *6 rad/s*
Knee (95%)	450	0.53	0.71	16 @ 2 rad/s	13 @ 2 rad/s	29 @ 2 rad/s
Knee (5%)	180	0.28	0.5	16(*)	15	31
Hip (95%)	450	4	4.62	55	0	55
Hip (5%)	180	1.4	3	20	10	30

(*) limited by acceleration safety limits.

Table 3.1.2.2.3.1.4 - Acceleration times

In the situations where the limiting factor for Ramp time is safety, MARES shall control this acceleration to stay below the limit, to avoid that the monitoring circuitry stops unnecessarily the movement.

Table 3.1.2.2.3.1.4 - Acceleration times, is limited to the maximum torque's and velocities. The Figure 3.1.2.2.3.1.4 - MARES ramp times calculation graph, allows to determine the Ramp time, given the opposing eccentric Torque, the desired target Velocity, and total moment of inertia (Limb+Human adapter).

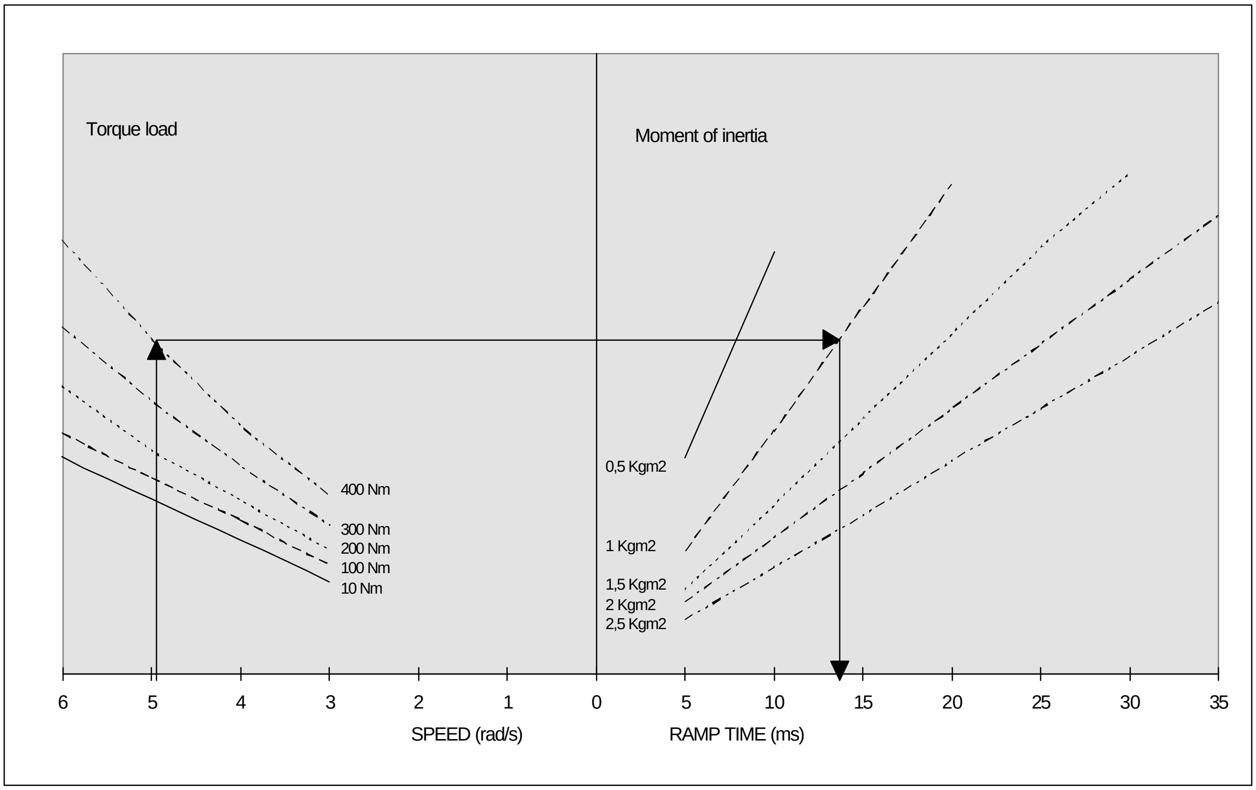


Figure 3.1.2.2.3.1.4 - MARES ramp times calculation graph

For any movement and under any Torque/Velocity/Position combination, the Velocity Stabilisation time defined above shall always stay under the 30 ms.

3.1.2.2.3.1.5 Quantification error

The applicable MARES Payload Software Specification, MARES-SP-007-, requires that it shall be possible to define some of the BMU parameters as a wave, that is a function of time, instead of as fixed values.

It shall be possible to select the origin of this wave using: a mathematical function, a table of data points, and an acquired signal (via the Parameter Set input of MARES). When MARES will use this wave in the BMU, the wave will always be digitised. This digitalisation process will introduce a quantification error.

MARES shall digitise these waves at no less than 100 samples/s and 12 bit resolutions.

MARES shall not introduce a quantification error larger than the quantification error corresponding to the above resolutions, mathematically calculated.

This quantification error shall not be included in the error figures required for each BMU mode.

3.1.2.2.3.2 Isometric BMU performance

3.1.2.2.3.2.1 Position setting

It shall be possible to select an angular Position within the range defined in 3.1.2.2.3.1, and with a resolution of 1°, and a linear Position with a resolution of 1 mm.

3.1.2.2.3.2.2 Isometric BMU Steady State Accuracy

In Steady State, the difference between the target and the measured angular Position (Angular Position Error) shall be lower than ±0.5°, with an applied subject Torque lower than 40 Nm.

In Steady State, the Angular Position Error shall always be lower than ±1°, with an applied Torque lower than 450Nm.

In Steady State, the difference between the target and the actual linear Position (Linear Position Error) shall be lower than ±1 mm, with an applied subject Force lower than 250 Nm, and in case this Linear Position Error is a vibration with significant frequency components (3 dB) at frequencies higher than 0.1 Hz.

In Steady State, the Linear Position Error shall always be lower than ±2 mm, with an applied Force lower than 250N.

This Steady State shall be maintained until the End condition of the BMU.

3.1.2.2.3.3 Isokinetic BMU performance

3.1.2.2.3.3.1 Velocity setting

It shall be possible to select any Velocity within the range defined in 3.1.2.2.3.1, and with an angular resolution of 5°/s, and a linear resolution of 0.5 cm/s.

3.1.2.2.3.3.2 Velocity settle time

The set Velocity shall comply with the acceleration times defined in previous section 3.1.2.2.3.1.4.

3.1.2.2.3.3.3 Velocity Overshoot

During the Ramp time period, the measured Velocity shall not go beyond the 135 % of the target Velocity.

3.1.2.2.3.3.4 Isokinetic BMU Steady State Accuracy.

In Steady State, with an applied Torque/Force within the Continuous Limits defined in 3.1.2.2.3.1 and not changing faster than 1 Nm/ms, the difference between the target and the measured Velocity (Velocity Error) shall always be lower than:

In angular movements:

- ±[4°/s + 4 % of |the target value|],
- ±[2°/s + 2 % of |the target value|], when filtered by a 10 Hz LPF.
- ±[2°/s + 1 % of |the target value|], when filtered by a 5 Hz LPF.

In linear movements:

- ± 5mm/s

This Steady State shall be maintained until the End condition of the BMU.

3.1.2.2.3.4 Isotonic BMU performance

3.1.2.2.3.4.1 Torque and force setting

It shall be possible to select a subject Torque and a Shaft torque within the ranges defined in 3.1.2.2.3.1, and with the following resolution:

Target Torque range (Nm)	Resolution (Nm)
0-60	1
60-300	1
300-450	5
>450	10

It shall be possible to select a Force with 1 N resolution.

3.1.2.2.3.4.2 Torque/force settle time

The Torque/Force Total Settle time is defined as the time that the Torque/Force parameter will take to go: from 5% of any target Torque/Force step (of less than 450 Nm and 250 N, respect.), until when it enters into Steady State.

The Torque/Force Total Settle time shall stay under the 30 ms.

3.1.2.2.3.4.3 Torque/force overshoot

During the Torque/Force Total Settle time period, the Torque/Force shall not go beyond the 140 % of the target Torque step.

3.1.2.2.3.4.4 Isotonic BMU Steady State Accuracy

In Steady State, with Velocities within the limits defined in 3.1.2.2.3.1, the difference between the target and the measured Torque/Shaft torque (Torque Error) shall always be lower than:

- ±[Ripple Torque + 6% of |the target value|].
- ±[Ripple Torque + 2% of |the target value|], when filtered by a 10 Hz LPF.
- ±[Ripple Torque + 1% of |the target value|], when filtered by a 5 Hz LPF.

where Ripple Torque, in angular movements, is equivalent to:

Target Torque Range (Nm)	**Ripple Torque**
2-60	0.3 Nm
60-300	1.4 Nm
300-450	3 Nm
>450	10%

In Steady State, with Velocities within the limits defined in 3.1.2.2.3.1, the difference between the target and the actual Force (Force Error) shall always be lower than:

- ±5% of |the target value|, for Forces between 5 and 250 N.
- ±0.5 N, for Forces below 5 N.

This Steady State shall be maintained until the End condition of the BMU.

3.1.2.2.3.5 Pseudo-gravitational BMU performance

The Mass, Radius and Gravity ranges defined here below are simultaneously compatible unless the resulting Torque and Force are higher than 450 Nm and 250N, respectively.

3.1.2.2.3.5.1 Mass setting

It shall be possible to select the value of the simulated Mass parameter from the following ranges:

- 1 to 40 Kg, placed at Radius of the motor shaft,.
- 1 to 100 Kg, in linear movements.

and with a resolution of 1 Kg in both cases.

In angular movements, it shall be possible to select the value of the Radius, that is the distance of the simulated Mass C.o.G. to the centre of the motor shaft, from the 100 to 1000 mm range, and with a resolution of 10 mm.

3.1.2.2.3.5.2 Gravity setting

It shall be possible to select the intensity of the simulated Gravity Vector from the 0.1 g to 3 g range, and with a resolution of 0.1 g, being “g” the Earth gravity.

It shall be possible to select the direction of the simulated Gravity Vector from the 0° to 360° range, and with a resolution of 1°.

3.1.2.2.3.5.3 Mass Settle time

When the Mass parameter is programmed to dynamically change in steps, the Pseudo-gravitational Total Settle time shall stay under the 70 ms.

The Pseudo-gravitational Total Settle time is defined as the time that the Actual Mass parameter will take to go: from 5% of any target Mass step, until entering into the Steady State, as defined below.

The Actual Mass parameter mentioned in the previous paragraph is the quotient of actual Torque/Force divided by actual Acceleration parameters.

3.1.2.2.3.5.4 Mass Overshoot

During the Pseudo-gravitational Total Settle time period the measured Mass shall not go beyond the 140 % of the target Mass step.

3.1.2.2.3.5.5 Pseudo-gravitational BMU Steady State Accuracy

In angular movements Steady State, with Velocities within the limits defined in 3.1.2.2.1, the target Torque to be applied by MARES shall follow the equation

$$T = R * M * g * \cos(\alpha - \alpha_g) + 1/2 * M * R^2 * \alpha''$$

Where:

T is the Torque (Nm)

R is the distance between the mass CoG and the motor shaft axis (m)

M is the mass (Kg)

g is the gravity (m/sec^2) and α_g is the gravity vector direction (rad)

α is the Position and α'' the Acceleration (rad, rad/sec^2)

In Steady State, with Velocities within the limits defined in3.1.2.2.1, the difference between the target and the measured Torque shall be lower than:

- $\pm$ [7 * 1/2 * M * R^2 + 6% of |the target value|]
- $\pm$[7 * 1/2 * M * R^2+ 2% of |the target value|], when filtered by a 10 Hz LPF.
- $\pm$[7 * 1/2 * M * R^2+ 1% of |the target value|], when filtered by a 5 Hz LPF.

In linear movements Steady State, with Velocities within the limits defined in 3.1.2.2.1, the target Force to be applied by MARES shall follow the equation:

$$F = M * g * \cos(\alpha_g) + M * a$$

Where:

F is the Force (N)

M is the mass (Kg)

g is the gravity (m/sec^2) and α_g is the gravity vector direction (rad)

a is the Acceleration (m/sec^2)

In Steady State, with Velocities within the limits defined in 3.1.2.2.1, the difference between the target and the measured Force shall be lower than

- $\pm$ [M + 6% of |the target value|]

This Steady State shall be maintained until the End condition of the BMU.

3.1.2.2.3.5.6 Mass bandwidth

When the Mass parameter is due to dynamically change following a programmable wave, MARES shall be able to control the Actual Mass parameter to follow any wave function with frequency components up to 1 Hz.

3.1.2.2.3.6 Position control BMU performance

3.1.2.2.3.6.1 Position setting

It shall be possible to select any angular Position within the range defined in 3.1.2.2.3.1.

3.1.2.2.3.6.2 Position Settle time

When the Position parameter is programmed to dynamically change in steps, the Position control Total Settle time is defined as the time that the actual Position parameter will take to go: from 5% of any target Position step, until entering into the Steady State, as defined below.

The Position control Total Settle time shall be shorter than the Total Settle times defined in the next section.

3.1.2.2.3.6.2.1 Rate of Change

In angular and linear motions, the Rate of Change of the Position parameter is a function both, of the actual delta angle/distance required, and of the M.o.I's/inertia's of the subject's limb and of the Human adapter.

Table 3.1.2.2.3.6.2.1 - Rate of Change and Total Settle times of the Position parameter, defines the Rate of Change for some extreme cases, covering all movements, and depending on the range of the Position step.

The actual Rate of Change of Position shall not be slower (higher times) than the values in Table 3.1.2.2.3.6.2.1 - Rate of Change and Total Settle times of the Position parameter, for the conditions included there.

Movement	for Position changes of	Rate of Change (ms / °)	Total Settle time (ms)
Ankle	Up to 13°	5	$5*\Delta\theta$
	over 13°	3	$3*\Delta\theta + 65$
Elbow	Up to 45°	5	$5*\Delta\theta$
	over 45°	3	$3*\Delta\theta + 225$
Shoulder	Up to 100°	5	$5*\Delta\theta$
	over 100°	3	$3*\Delta\theta + 500$

Wrist	any	5	5*Δθ
Knee	Up to 50°	5	5*Δθ
	over 50°	3	3*Δθ + 250
Hip	any	5	5*Δθ
Trunk	any	5	5*Δθ
Linear	any	2 ms/mm	2*Δdistance

Table 3.1.2.2.3.6.2.1 - Rate of Change and Total Settle times of the Position parameter

3.1.2.2.3.6.2.2 Position control BMU accuracy in transitions

MARES shall be able to follow within the Steady State Accuracy defined below, any transition on the wave defining the target Position parameter, if the straight line interpolating two consecutive data points of this wave has a slope slower than the Rate of Change of 5 ms / ° or 2 ms/mm defined above.

For transitions sharper than the ones defined in the previous paragraph, MARES still has to try to follow the target wave with a rate not slower than this 5 ms / ° or 2 ms/mm, but there are no specific accuracy requirements.

3.1.2.2.3.6.3 Position control BMU Steady State Accuracy

In Steady State, that is for target Positions not changing faster than the 5 ms / ° Rate of Change between two consecutive data points, the difference (Angular Position Error) between this digitised target, after being filtered by the frequency response shown in **Error! Unknown switch argument.**, and the measured angular Position, shall be lower than ±1°, with an applied Torque lower than 40 Nm.

In Steady State, the Angular Position Error shall always be lower than ±2°, with an applied Torque lower than 450Nm.

In Steady State, that is for target Positions not changing faster than the 2 ms /mm Rate of Change between two consecutive data points, the difference between the target and the measured linear Position (Linear Position Error) shall be lower than ±1 mm, with an applied subject Force lower than 250 N, and in case this Linear Position Error is a vibration with significant frequency components (3 dB) at frequencies higher than 0.1 Hz.

In Steady State, the Linear Position Error shall always be lower than ±2 mm, with an applied Force lower than 250N.

This Steady State shall be maintained until the End condition of the BMU.

3.1.2.2.3.6.4 Position bandwidth

MARES shall be able to control the actual Position parameter to follow, within the Steady State Accuracy defined above, any wave function with frequency components up to 10 Hz, after being filtered by the frequency response shown below, in Figure 3.1.2.2.3.6.4 - Amplitude response, and provided the slope between two consecutive samples (being generated at 100 samples/s) is lower than the Rate of Change.

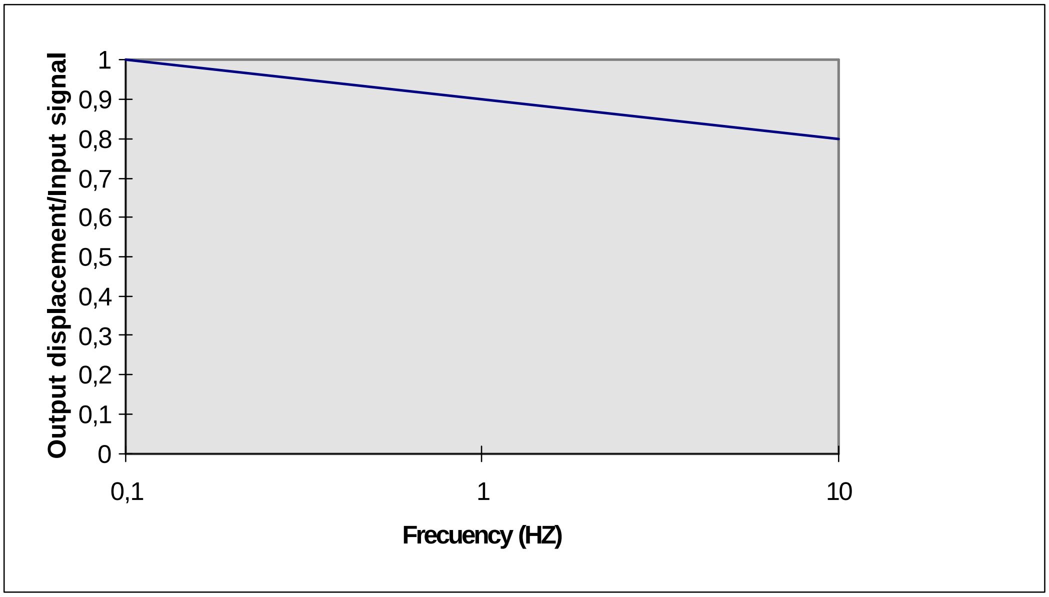


Figure 3.1.2.2.3.6.4 - Amplitude response

3.1.2.2.3.7 Velocity control BMU performance

3.1.2.2.3.7.1 Velocity setting

It shall be possible to select any Velocity within the range defined in 3.1.2.2.3.1.

3.1.2.2.3.7.2 Velocity settle time

When the Velocity parameter is programmed to dynamically change in steps, the actual Velocity shall comply with the acceleration times defined in section 3.1.2.2.3.1.4 of this HRD.

3.1.2.2.3.7.3 Velocity Overshoot

During the Ramp time period, the measured Velocity shall not go beyond the 135 % of the target Velocity.

3.1.2.2.3.7.4 Velocity control BMU Steady State Accuracy.

In Steady State, with an applied Torque/Force within the Continuous Limits defined in 3.1.2.2.3.1, not changing with peak to peak amplitudes greater than 20% of the nominal maximum torque of the exercised joint, and with frequency components up to 10 Hz, the difference between the target and the measured Velocity (Velocity Error) shall always be lower than:

In angular movements:

- ±[4°/s + 4 % of |the target value|],
- ±[2°/s + 2 % of |the target value|], when filtered by a 10 Hz LPF.
- ±[2°/s + 1 % of |the target value|], when filtered by a 5 Hz LPF.

In linear movements:

- ±5 mm/s.

This Steady State shall be maintained until the End condition of the BMU.

3.1.2.2.3.7.5 Speed control bandwidth

MARES shall provide a flat speed control bandwidth of up to 10 Hz.

3.1.2.2.3.8 Torque/force control BMU performance

The torque/force control BMU has to comply with the requirements of the Isotonic BMU in section 3.1.2.2.3.4.

3.1.2.2.3.8.1 Torque/force control bandwidth

MARES shall provide a flat torque/force control bandwidth for target wave functions with frequency components up to 10 Hz.

3.1.2.2.3.9 Power control BMU performance

3.1.2.2.3.9.1 Power setting

It shall be possible to select the Power parameter from the 10 Watt to 1600 Watt range, and with a resolution of 10 Watt, for angular movements.

It shall be possible to select the Power parameter from the 1 Watt to 125 Watt range, and with a resolution of 1 Watt, for linear movements.

3.1.2.2.3.9.2 Power Settle time

When the Power parameter is programmed to dynamically change in steps, the Power Total Settle time shall stay under the 70 ms.

The Power Total Settle time is defined as the time that the Actual Power parameter will take to go: from 5% of any target Power step, until entering into the Steady State, as defined below.

The Actual Power parameter mentioned in the previous paragraph is the multiplication of actual Torque/Force by the actual Velocity parameters.

3.1.2.2.3.9.3 Power Overshoot

During the Power Total Settle time period, the measured Power shall not go beyond the 140 % of the target Power step.

3.1.2.2.3.9.4 Power BMU Steady State Accuracy

In Steady State, with an applied Torque/Force and Velocities within the Continuous Limits defined in 3.1.2.2.3.1, the difference between the target and the measured Power (Power Error) shall be lower than:

- ±[1 Watt + 10% of |the target value|].
- ±[1 Watt + 4% of |the target value|], when filtered by a 10 Hz LPF.
- ±[1 Watt + 2% of |the target value|], when filtered by a 5 Hz LPF.

This Steady State shall be maintained until the End condition of the BMU.

3.1.2.2.3.9.5 Power bandwidth

When the Power parameter is due to dynamically change following a programmable wave, MARES shall be able to control the Actual Power parameter to follow any wave function with frequency components up to 1 Hz.

3.1.2.2.3.10 Physical elements BMU performance

The following specifications shall also apply to Spring, Friction, and Additional Moment Of Inertia/Inertia BMU modes. In these BMUs, the capabilities of the theoretical evolution of the basic parameters (Torque/Force, Shaft torque, Velocity, Position, Power) shall be limited only by the limits defined in 3.1.2.2.3.1 of this HRD.

3.1.2.2.3.10.1 Elements Setting

It shall be possible to select if this algorithm applies before or after the human adapter, this means that the target torque refers to subject Torque or alternatively to the Shaft Torque.

It shall be possible to set a spring coefficient between ±0.5 and ±70 Nm/° for angular movements and between 10 and 1500 N/m for linear movements, with a resolution of 0.5 Nm/° and of 10 N/m, respectively.

It shall be possible to set a friction coefficient between 1 and 120 Nm/(rad/s) in angular movements and between 2 and 240 N/(m/s) for linear movements, with a resolution of 1 Nm/(rad/s)and of 2 N/(m/s), respectively.

It shall be possible to set an additional moment of inertia between ±0.01 and ±700 kgm^2. It shall be possible to set an additional inertia between ±0.01 and ±25 Kg, with a resolution of 0.01 kgm^2 and of 0.01 Kg, respectively. The addition of the moment of inertia/inertia of the subject to this inertia element shall always be positive.

3.1.2.2.3.10.2 Elements-Torque/Force Settle time

When starting the Physical elements BMU, the Elements-Torque/Force Total Settle time shall stay under the 70 ms.

The Elements-Torque/Force Total Settle time is defined as the time that the actual Torque/Force parameter will take to go: from 5% of the resulting Torque/Force step, until entering into the Steady State, as defined below.

3.1.2.2.3.10.3 Elements Steady state accuracy.

In Steady State, with an applied Torque/Shaft torque/Force and Velocities within the Continuous Limits defined in 3.1.2.2.3.1, the target Torque/Force to be applied by MARES shall follow the equation

$$T/F(t) = K * \alpha(t) + B * \alpha'(t) + J * \alpha''(t)$$

from whatever the Velocity and Position values were when the BMU was started.

Where: T/F is the Torque/Force

K is the spring coefficient

B is the friction coefficient

J is the moment of inertia/inertia

α is the Position, α' is the Velocity and α'' is the Acceleration.

In Steady State, the difference between the target Torque/Force and the measured Torque/Force (Elements-Torque/Force Error) shall be lower than:

- ± [0.1*K + 0.01*B + 7*J + 6% |of the target value|] for torque's,
- ± [0.1*K + 0.01*B + 1*J + 6% |of the target value|] for forces,
- ± [Ripple + 4% |of the target value|], when filtered by a 10 Hz LPF.
- ± [Ripple + 2% |of the target value|], when filtered by a 5 Hz LPF.

Being Ripple equal to:

Ripple Torque defined in 3.1.2.2.3.4.4, for Torque's.

0.5 N, for Forces.

This Steady State shall be maintained until the End condition of the BMU.

3.1.2.2.3.10.4 Elements bandwidth

When one of the Element coefficients is due to dynamically change following a programmable wave, MARES shall be able to stay in Steady State even if the coefficient wave function has frequency components of up to 1 Hz.

3.1.2.2.3.11 Extended torque/force control BMU performance

The Extended torque/force control BMU shall comply with the setting capabilities and the accuracy requirements defined for the Torque/force control BMU in 3.1.2.2.3.8, and with the requirements defined for the Physical elements BMU in 3.1.2.2.3.10, of this HRD.

3.1.2.2.3.12 Quick release BMU performance

In the Quick release BMU, when entering the Release phase, the residual Shaft torque and Torque between the Human adapter and the subject shall be within:

- $\pm$ 20 Nm, after 5 ms+3µs/IT from T0
- $\pm$ 5 Nm, after 20 ms+3µs/IT from T0

for velocities lower than 8.8 rad/s and for accelerations of up to 500 rad/s^2, where:

T0 is the beginning of the release phase, defined as when the velocity first reaches 0.1 rad/s

IT is the initial Torque exerted isometrically by the subject at T0.

To give an indication of what those torque bands mean:

$\pm$ 20 Nm is equivalent to 0.2 kgm^2 of residual inertia @ $\pm$ 100 rad/s^2

$\pm$ 5 Nm is equivalent to 0.05 kgm^2 of residual inertia @ $\pm$ 100 rad/s^2.

3.1.2.2.4 Human adapters

3.1.2.2.4.1 Definition of terms

3.1.2.2.4.1.1 Neutral body position

The neutral position of the subject is presented in Figure 3.1.2.2.4.1.1 - Subject neutral anatomical position. This position is extracted from the chapter **Overview of Anatomy,** from the book **Clinically Oriented Anatomy** by Keith L. Moore.

All other body positions will be defined by identifying the deviations on the angles of all joints, from this neutral position.

Subject in neutral anatomical position :

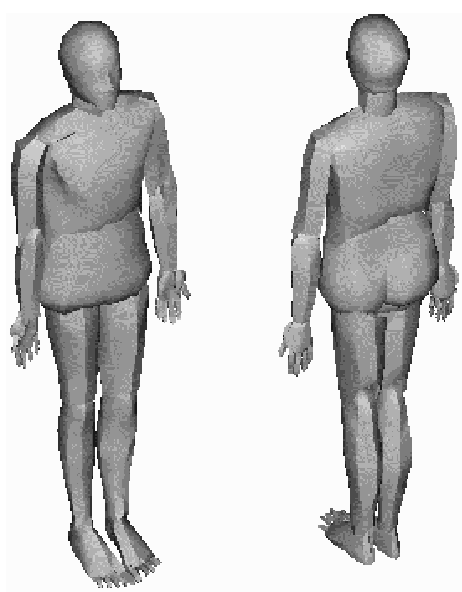


Figure 3.1.2.2.4.1.1 - Subject neutral anatomical position

3.1.2.2.4.1.2 Angle conventions

For the identification of these deviations in joint angles the following conventions are used:

- 0° corresponds to the neutral position

- Positive angles (+) correspond to flexion, dorsal flexion, abduction, pronation, right rotation, internal and counter-clockwise rotation, with respect to the neutral position.
- Negative angles (-) correspond to extension, plantar flexion, adduction, supination, left rotation, external and clockwise rotation, with respect to the neutral position.
- When a limb is referred as E side, it refers to the limb in the exercising side of the subject. When referred as R side it refers to the resting side.

3.1.2.2.4.1.3 Body joints

The position of the subject is defined by defining the following joint angles:

- Ankle dorsi-plantar flexion
- Ankle eversion (pronation)/ inversion (supination)
- Knee flexion-extension
- Knee internal (medial)/ external (lateral) rotation. This movement is only possible when the knee is flexed. With the knee totally extended, this movement is not possible
- Hip flexion-extension
- Hip abduction-adduction
- Hip internal(medial)/external(lateral) rotation.
- Trunk flexion-extension
- Trunk lateral right/left rotation. Right indicates that the movement tends to put thorax oriented towards the subject’s right side. Left indicates that the thorax is oriented towards the subject’s left side.
- Trunk lateral right/left flexion (inclination). A lateral right flexion implies a lateral bending of the trunk on the subject’s right side. A lateral left flexion implies a lateral bending of the trunk on the subject’s left side.
- Wrist pronation-supination (prono-supination)
- Wrist flexion-extension
- Wrist radial-ulnar deviation
- Elbow flexion-extension

- Shoulder flexion-extension
- Shoulder abduction-adduction
- Shoulder rotation. This rotation can be counter-clockwise or clockwise according to what is seen by the subject of the experiment.
- Neck flexion-extension
- Neck right/left rotation. Left rotation of the neck is that rotation that moves the face towards the subject's left side. Right rotation of the neck is that rotation that moves the face towards the subject's right side.

Another three angles are added to define the position of the subject with respect to the gravity vector during ground exercises, and for the linear movements:

- The angle G1 refers to the angle between the line contained in the horizontal plane at the thorax that crosses the body by the two Acromia (shoulder line), and the gravity vector (G) in ground operations. It is 90° in neutral and supine positions.
- The angle G2 refers to the angle between the line contained in the median plane perpendicular to the floor when the subject is in standing position (spine line), and the gravity vector (G). It is 0° in neutral and 90° in supine, positions.
- The angle L1 refers to the angle between the linear movement trajectory and the line contained in the median plane perpendicular to the floor when the subject is in standing position (spine line). For Leg Linear fully extended: it is 180° in supine and 90° in seated, positions. For Arm Linear fully extended: it is 90° in supine-press and 0° in overhead-press.

3.1.2.2.4.2 Subject nominal positions

MARES shall be able to support, for each of the required movements, the subject nominal body positions defined in the following tables in the "Nominal position" column.

Wherever a range is defined in this column, instead of a fixed angle, this joint/degree of freedom corresponds to a secondary joint adjustment. The resolution of this adjustment shall be the resolution defined in the "Setting" column.

The column "Range" is not a requirement, it is meant to give just an idea on what the actual covered range could be.

The included figures are not a requirement, they are only shown to help understand the nominal body positions.

3.1.2.2.4.2.1 Ankle dorsi-plantar flexion

Joint	Type of joint	Degree of freedom	Range	Setting	Nominal position
Ankle	Main	**Dorsi-Plantar Flexion**	ROM selected with end-stops from 360°	The end positions of ROM are selectable in 2,5° steps	ROM selected with end-stops from 360°
			From -10° to 30° in resting limb	Steps	0°
Ankle	Other	**Eversion-Inversion**	0°	Fixed	0°
Knee	Secondary	**Flexion-Extension**	For exercising limb from 0° to 90°	For exercising limb, steps 5°	0° to 90°
			For resting limb from 80° to 90°	For resting limb, steps	90°
Knee	Other	**Internal-External Rotation**	From -10° to 10°, for exercising limb	Fixed	0°
			For resting limb From -10° to 10°	For resting limb, steps	0°
Hip	Other	**Flexion-Extension**	0° to 90°	Steps 5°	dependent on Knee (0° to 90°)
Hip	Other	**Abduction - Adduction**	0°	Fixed	0°
Hip	Other	**Internal-External Rotation**	0°	Fixed	0°
Trunk	Other	**Flexion-Extension**	0°	Fixed	0°
Trunk	Other	**Lateral Right/Left Rotation**	0°	Fixed	0°
Trunk	Other	**Lateral Right/Left Flexion**	0°	Fixed	0°
Wrist	Other	**Pronation-Supination**	not controlled		not controlled
Wrist	Other	**Flexion-Extension**	not controlled		not controlled
Wrist	Other	**Radial-Ulnar Deviation**	not controlled		not controlled
Elbow	Other	**Flexion-Extension**	not controlled		not controlled
Shoulder	Other	**Flexion-Extension**	not controlled		not controlled
Shoulder	Other	**Abduction - Adduction**	not controlled		not controlled
Shoulder	Other	**Rotation**	not controlled		not controlled
Neck	Other	**Flexion-Extension and Right-**	not controlled		Not controlled

		Left Rotation			
G1	Whole body		90°	Fixed	90°
G2	Whole body		0° to 90°	Steps 10°	90°

Table 3.1.2.2.4.2.1 - Ankle dorsi-plantar flexion body position.

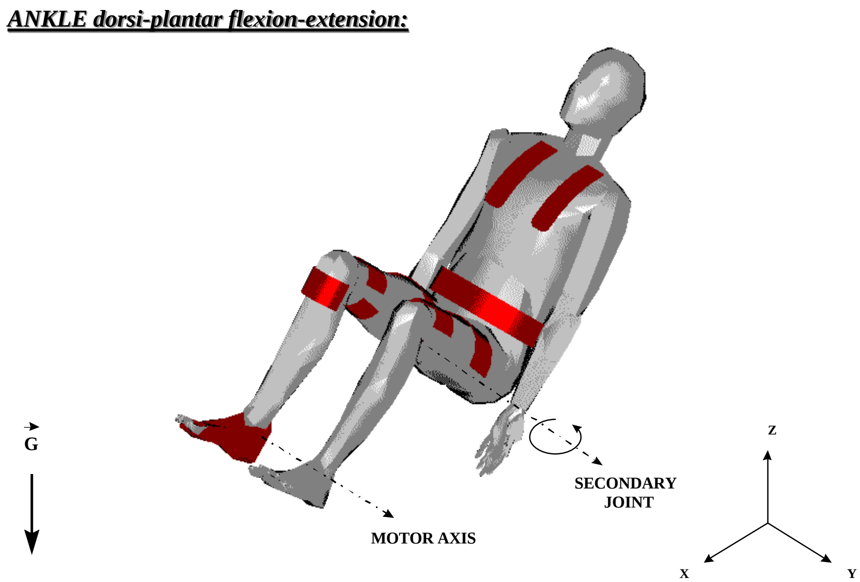


Figure 3.1.2.2.4.2.1 - Ankle dorsi-plantar flexion body position.

3.1.2.2.4.2.2 Knee flexion/extension

Joint	Type of joint	Degree of freedom	Range	Setting	Nominal position
Ankle	Other	**Dorsi-Plantar Flexion**	0° in exercising limb	Fixed	0°
			From -10° to 30° in resting limb	Steps	0°
Ankle	Other	**Eversion-Inversion**	0°	Fixed	0°
Knee	Main	**Flexion-Extension**	ROM selected with end-stops from 360°	The end positions of ROM are selectable in 2,5° steps	ROM selected with end-stops from 360°
			For resting limb from 80° to 90°	For resting limb, steps 5°	For resting limb from 80° to 90°
Knee	Other	**Internal-External Rotation**	0° for exercising limb	Fixed	0°
			For resting limb From -10° to 10°	For resting limb, steps	0°
Hip	Secondary	**Flexion-Extension**	0° to 90°	Steps 5°	0° to 90°
Hip	Other	**Abduction - Adduction**	0°	Fixed	0°
Hip	Other	**Internal-External Rotation**	0°	Fixed	0°
Trunk	Other	**Flexion-Extension**	0°	Fixed	0°
Trunk	Other	**Lateral Right/Left Rotation**	0°	Fixed	0°
Trunk	Other	**Lateral Right/Left Flexion**	0°	Fixed	0°
Wrist	Other	**Pronation-Supination**	not controlled		not controlled
Wrist	Other	**Flexion-Extension**	not controlled		not controlled
Wrist	Other	**Radial-Ulnar Deviation**	not controlled		not controlled
Elbow	Other	**Flexion-Extension**	not controlled		not controlled
Shoulder	Other	**Flexion-Extension**	not controlled		not controlled
Shoulder	Other	**Abduction - Adduction**	not controlled		not controlled
Shoulder	Other	**Rotation**	not controlled		not controlled
Neck	Other	**Flexion-Extension and Right-Left Rotation**	not controlled		not controlled
G1	Whole body		90°	Fixed	90°

G2	Whole body		0° to 90°	Steps 10°	Dependent on Hip: from 60° to 90°

Table 3.1.2.2.4.2.2 - Knee flexion-extension body position.

KNEE flexion-extension:

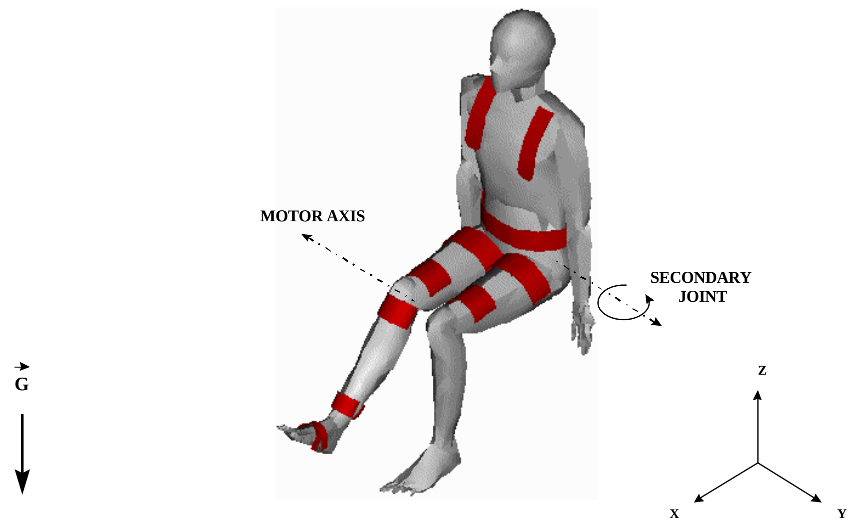


Figure 3.1.2.2.4.2.2 - Knee flexion-extension body position.

3.1.2.2.4.2.3 Hip flexion/extension

Joint	Type of joint	Degree of freedom	Range	Setting	Nominal position
Ankle	Other	**Dorsi-Plantar Flexion**	0° in exercising limb	Fixed	0°
			From -10° to 30° in resting limb	Steps (±2.5°)	0°
Ankle	Other	**Eversion-Inversion**	0°	Fixed	0°
Knee	Secondary	**Flexion-Extension**	From 0° to 90° on exercising limb	Steps 5°	0° to 90°
			For resting limb from 80° to 90°	For resting limb, steps 5°	For resting limb from 80° to 90°
Knee	Other	**Internal-External Rotation**	0° for exercising limb	Fixed	0°
			For resting limb from -10° to 10°	For resting limb, steps (±2,5°)	0°
Hip	Main	**Flexion-Extension**	ROM selected with end-stops from 360°	The end positions of ROM are selectable in 2,5° steps	ROM selected with end-stops from 360°
			0° on resting limb	Fixed	0°
Hip	Other	**Abduction - Adduction**	0°	Fixed	0°
Hip	Other	**Internal-External Rotation**	0°	Fixed	0°
Trunk	Other	**Flexion-Extension**	0°	Fixed	0°
Trunk	Other	**Lateral Right/Left Rotation**	0°	Fixed	0°
Trunk	Other	**Lateral Right/Left Flexion**	0°	Fixed	0°
Wrist	Other	**Pronation-Supination**	not controlled		not controlled
Wrist	Other	**Flexion-Extension**	not controlled		not controlled
Wrist	Other	**Radial-Ulnar Deviation**	not controlled		not controlled
Elbow	Other	**Flexion-Extension**	not controlled		not controlled
Shoulder	Other	**Flexion-Extension**	not controlled		not controlled
Shoulder	Other	**Abduction - Adduction**	not controlled		not controlled
Shoulder	Other	**Rotation**	not controlled		not controlled
Neck	Other	**Flexion-Extension and Right-Left Rotation**	0°	Fixed	0°

G1	Whole body		90°	Fixed	90°
G2	Whole body		90°	Fixed	90°

Table 3.1.2.2.4.2.3 - Hip flexion-extension body position.

HIP flexion-extension:

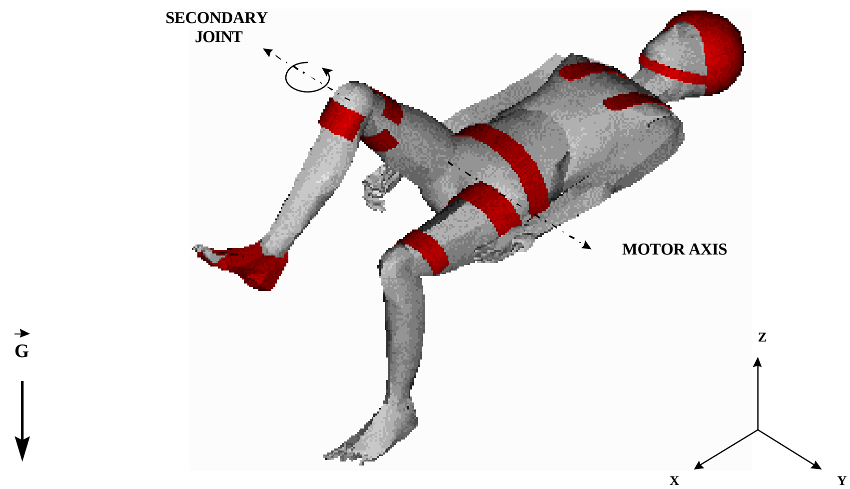


Figure 3.1.2.2.4.2.3 - Hip flexion-extension body position.

3.1.2.2.4.2.4 Wrist flexion/extension

Joint	Type of joint	Degree of freedom	Range	Setting	Nominal position
Ankle	Other	**Dorsi-Plantar Flexion**	From -10° to 30°	Steps	0°
Ankle	Other	**Eversion-Inversion**	0°	Fixed	0°
Knee	Other	**Flexion-Extension**	From 80° to 90°	Steps	90°
Knee	Other	**Internal-External Rotation**	From -10° to 10°	Steps	0°
Hip	Other	**Flexion-Extension**	25° to 90° . The single position 0° is also available	Steps	0°
Hip	Other	**Abduction - Adduction**	0°	Fixed	0°
Hip	Other	**Internal-External Rotation**	0°	Fixed	0°
Trunk	Other	**Flexion-Extension**	0°	Fixed	0°
Trunk	Other	**Lateral Right/Left Rotation**	0°	Fixed	0°
Trunk	Other	**Lateral Right/Left Flexion**	0°	Fixed	0°
Wrist	Other	**Pronation-Supination**	Two possible positions in exercising limb: 180° and 0°	Fixed	180°
			not controlled in resting side		not controlled
Wrist	Main	**Flexion-Extension**	ROM selected with end-stops from 360°	The end positions of ROM are selectable in 2.5° steps	ROM selected with end-stops from 360°
			not controlled in resting side		not controlled
Wrist	Other	**Radial-Ulnar Deviation**	0° in exercising limb	Fixed	0°
			not controlled in resting limb		not controlled
Elbow	Secondary	**Flexion-Extension**	0° to 90° on exercising limb	Steps	0° to 90°
			not controlled in resting limb		not controlled
Shoulder	Other	**Flexion-Extension**	0° to 25° on exercising limb	Steps	0°
Shoulder	Other	**Abduction - Adduction**	0° in exercising limb	Fixed	0°
			not controlled in resting limb		not controlled
Shoulder	Other	**Rotation**	0° in exercising limb	Fixed	0°
			not controlled in resting limb		not controlled
Neck	Other	**Flexion-Extension and Right-Left Rotation**	not controlled		not controlled
G1	Whole body		90°	Fixed	90°

G2	Whole body		0° to 65° and a discrete position of 90°	Steps	90°

Table 3.1.2.2.4.2.4 - Wrist flexion/extension body position.

WRIST flexion-extension :

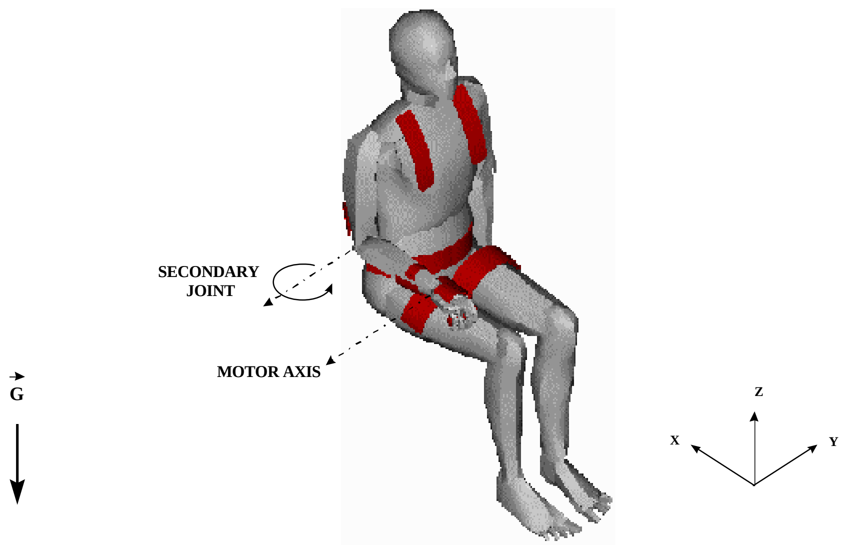


Figure 3.1.2.2.4.2.4 - Wrist flexion/extension body position.

3.1.2.2.4.2.5 Wrist pronation-supination

Joint	Type of joint	Degree of freedom	Range	Setting	Nominal position
Ankle	Other	**Dorsi-Plantar Flexion**	From -10° to 30°	Steps	0°
Ankle	Other	**Eversion-Inversion**	0°	Fixed	0°
Knee	Other	**Flexion-Extension**	From 80° to 90°	Steps	90°
Knee	Other	**Internal-External Rotation**	From -10° to 10°	Steps	0°
Hip	Other	**Flexion-Extension**	25° to 90° (±5°)	Steps 5°	dependent on Elbow (25° to 90°)
Hip	Other	**Abduction - Adduction**	0°	Fixed	0°
Hip	Other	**Internal-External Rotation**	0°	Fixed	0°
Trunk	Other	**Flexion-Extension**	0°	Fixed	0°
Trunk	Other	**Lateral Right/Left Rotation**	0°	Fixed	0°
Trunk	Other	**Lateral Right/Left Flexion**	0°	Fixed	0°
Wrist	Main	**Pronation-Supination**	ROM selected with end-stops from 360°	The end positions of ROM are selectable in 2.5° steps	ROM selected with end-stops from 360°
			not controlled on resting side		not controlled
Wrist	Other	**Flexion-Extension**	0° in exercising limb	Fixed	0°
			not controlled in resting side		not controlled
Wrist	Other	**Radial-Ulnar Deviation**	0° in exercising limb	Fixed	0°
			not controlled in resting limb		not controlled
Elbow	Secondary	**Flexion-Extension**	0° to 90° (±2,5°) in exercising lim	Steps 5°	0° to 90°
			not controlled in resting limb		not controlled
Shoulder	Other	**Flexion-Extension**	0° to 25° (±2,5°) in exercising lim	Steps 5°	dependent on Elbow (0° to 25°)
			not controlled on resting limb		not controlled
Shoulder	Other	**Abduction - Adduction**	0° in exercising limb	Fixed	0°
			not controlled in resting limb		not controlled
Shoulder	Other	**Rotation**	0° in exercising limb	Fixed	0°
			not controlled in resting limb		not controlled
Neck	Other	**Flexion-Extension and Right-Left Rotation**	not controlled		not controlled
G1	Whole body		90°	Fixed	90°
G2	Whole body		0° to 65° (±2,5°)	Steps	0°

Table 3.1.2.2.4.2.5 **-** *Wrist pronation/supination body position.*

WRIST pronation-supination :

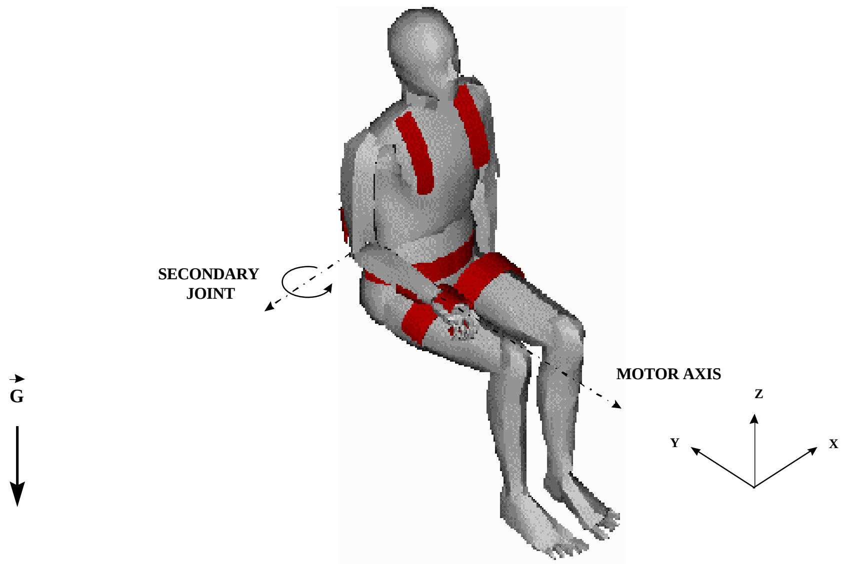


Figure 3.1.2.2.4.2.5 - Wrist pronation/supination body position.

3.1.2.2.4.2.6 Wrist radial-ulnar deviation

Joint	Type of joint	Degree of freedom	Range	Setting	Nominal position
Ankle	Other	**Dorsi-Plantar Flexion**	From -10° to 30°	Steps	0°
Ankle	Other	**Eversion-Inversion**	0°	Fixed	0°
Knee	Other	**Flexion-Extension**	From 80° to 90°	Steps	90°
Knee	Other	**Internal-External Rotation**	From -10° to 10°	Steps	0°
Hip	Other	**Flexion-Extension**	25° to 90° (±5°). The single position 0° is also available	Steps	0°
Hip	Other	**Abduction - Adduction**	0°	Fixed	0°
Hip	Other	**Internal-External Rotation**	0°	Fixed	0°
Trunk	Other	**Flexion-Extension**	0°	Fixed	0°
Trunk	Other	**Lateral Right/Left Rotation**	0°	Fixed	0°
Trunk	Other	**Lateral Right/Left Flexion**	0°	Fixed	0°
Wrist	Other	**Pronation-Supination**	90° on exercising limb	Fixed	90°
			not controlled in resting side		not controlled
Wrist	Other	**Flexion-Extension**	0° in exercising limb	Fixed	0°
			not controlled in resting side		not controlled
Wrist	Main	**Radial-Ulnar Deviation**	ROM selected with end-stops from 360°	The end positions of ROM are selectable in 2.5° steps	ROM selected with end-stops from 360°
			not controlled in resting limb		not controlled
Elbow	Secondary	**Flexion-Extension**	0° to 90° (±2,5°) in exercising limb	Steps 5°	0° to 90°
			not controlled in resting limb		not controlled
Shoulder	Other	**Flexion-Extension**	0° to 25° (±2,5°) in exercising limb	Steps	0°
			not controlled on resting limb		not controlled
Shoulder	Other	**Abduction - Adduction**	0° in exercising limb	Fixed	0°
			not controlled in resting limb		not controlled
Shoulder	Other	**Rotation**	0° in exercising limb	Fixed	0°
			not controlled in resting limb		not controlled
Neck	Other	**Flexion-Extension and Right-Left Rotation**	not controlled		not controlled
G1	Whole body		90°	Fixed	90°

G2	Whole body		0° to 65° (±2,5°) and a discrete position of 90°	Steps	90°

*Table 3.1.2.2.4.2.6 **-** Wrist radial/ulnar deviation body position.*

WRIST radial/ulnar deviation:

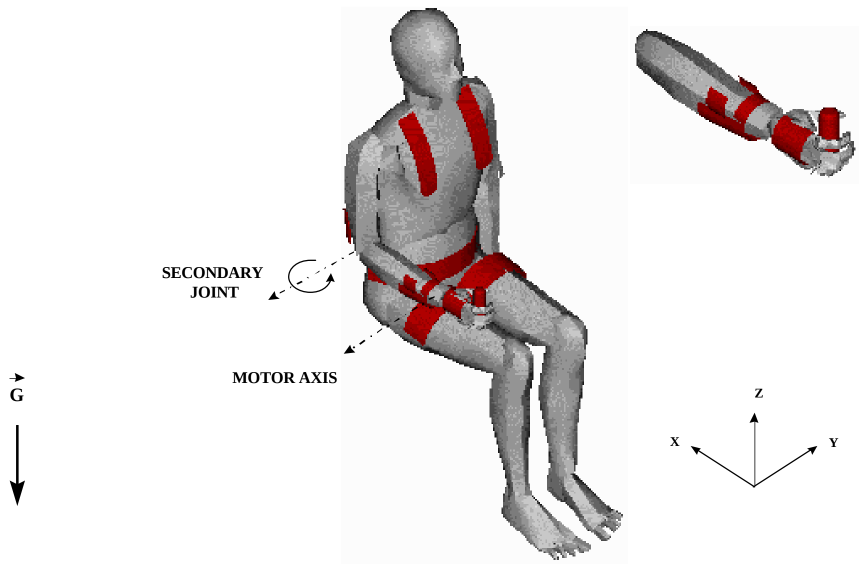


Figure 3.1.2.2.4.2.6 - Wrist radial/ulnar deviation body position.

3.1.2.2.4.2.7 Elbow flexion/extension

Joint	Type of joint	Degree of freedom	Range	Setting	Nominal position
Ankle	Other	**Dorsi-Plantar Flexion**	From -10° to 30°	Steps	0°
Ankle	Other	**Eversion-Inversion**	0°	Fixed	0°
Knee	Other	**Flexion-Extension**	From 80° to 90°	Steps	90°
Knee	Other	**Internal-External Rotation**	From -10° to 10°	Steps	0°
Hip	Other	**Flexion-Extension**	50°	Fixed	50°
Hip	Other	**Abduction - Adduction**	0°	Fixed	0°
Hip	Other	**Internal-External Rotation**	0°	Fixed	0°
Trunk	Other	**Flexion-Extension**	0°	Fixed	0°
Trunk	Other	**Lateral Right/Left Rotation**	0°	Fixed	0°
Trunk	Other	**Lateral Right/Left Flexion**	0°	Fixed	0°
Wrist	Secondary	**Pronation-Supination**	Two possible configurations in exercising limb: • Neutral prono-supination (90°) • Supine (0°)	Fixed	0° and 90°
			not controlled in resting side		not controlled
Wrist	Other	**Flexion-Extension**	0° in exercising limb	Fixed	0°
			not controlled in resting side		not controlled
Wrist	Other	**Radial-Ulnar Deviation**	0° in exercising limb	Fixed	0°
			not controlled in resting limb		not controlled
Elbow	Main	**Flexion-Extension**	ROM selected with end-stops from 360°	The end positions of ROM are selectable in 2.5° steps	ROM selected with end-stops from 360°
Shoulder	Other	**Flexion-Extension**	0°	Fixed	0°
Shoulder	Secondary	**Abduction - Adduction**	0° to 30° on exercising limb	Steps 5°	0° to 30°
			not controlled in resting limb		not controlled
Shoulder	Other	**Rotation**	0° in exercising limb	Fixed	0°
			not controlled in resting limb		not controlled
Neck	Other	**Flexion-Extension and Right-Left Rotation**	not controlled		not controlled
G1	Whole body		90°	Fixed	90°

G2	Whole body		90°	Fixed	90°

Table 3.1.2.2.4.2.7 - Elbow flexion/extension body position.

ELBOW flexion-extension:

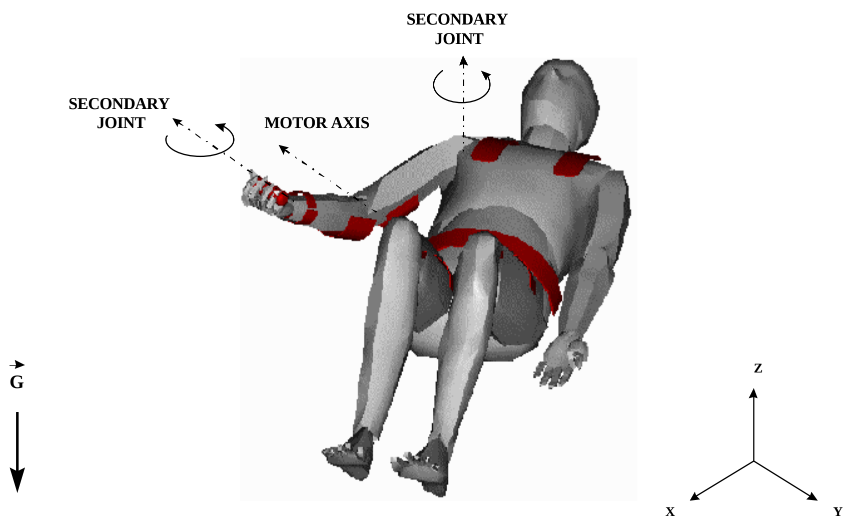


Figure 3.1.2.2.4.2.7 - Elbow flexion/extension body position.

3.1.2.2.4.2.8 Shoulder flexion/extension

Joint	Type of joint	Degree of freedom	Range	Setting	Nominal position
Ankle	Other	**Dorsi-Plantar Flexion**	From -10° to 30°	Steps	0°
Ankle	Other	**Eversion-Inversion**	0°	Fixed	0°
Knee	Other	**Flexion-Extension**	From 80° to 90°	Steps	90°
Knee	Other	**Internal-External Rotation**	From -10° to 10°	Steps	0°
Hip	Other	**Flexion-Extension**	50°	Fixed	50°
Hip	Other	**Abduction - Adduction**	0°	Fixed	0°
Hip	Other	**Internal-External Rotation**	0°	Fixed	0°
Trunk	Other	**Flexion-Extension**	0°	Fixed	0°
Trunk	Other	**Lateral Right/Left Rotation**	0°	Fixed	0°
Trunk	Other	**Lateral Right/Left Flexion**	0°	Fixed	0°
Wrist	Other	**Pronation-Supination**	Neutral prono-supination (90°) in exercising limb	Fixed	90°
			not controlled in resting side		not controlled
Wrist	Other	**Flexion-Extension**	0° in exercising limb	Fixed	0°
			not controlled in resting side		not controlled
Wrist	Other	**Radial-Ulnar Deviation**	0° in exercising limb	Fixed	0°
			not controlled in resting limb		not controlled
Elbow	Other	**Flexion-Extension**	30° in exercising limb	Fixed	30°
			not controlled in resting limb		not controlled
Shoulder	Main	**Flexion-Extension**	ROM selected with end-stops from 360°	The end positions of ROM are selectable in 2.5° steps	ROM selected with end-stops from 360°
Shoulder	Secondary	**Abduction - Adduction**	0° to 30° on exercising limb	Steps 5°	0° to 30°
			not controlled in resting limb		not controlled
Shoulder	Other	**Rotation**	0° in exercising limb	Fixed	0°
			not controlled in resting limb		not controlled
Neck	Other	**Flexion-Extension and Right-Left Rotation**	0°	Fixed	0°
G1	Whole body		90°	Fixed	90°

G2	Whole body		90°	Fixed	90°

Table 3.1.2.2.4.2.8 **-** *Shoulder flexion/extension body position.*

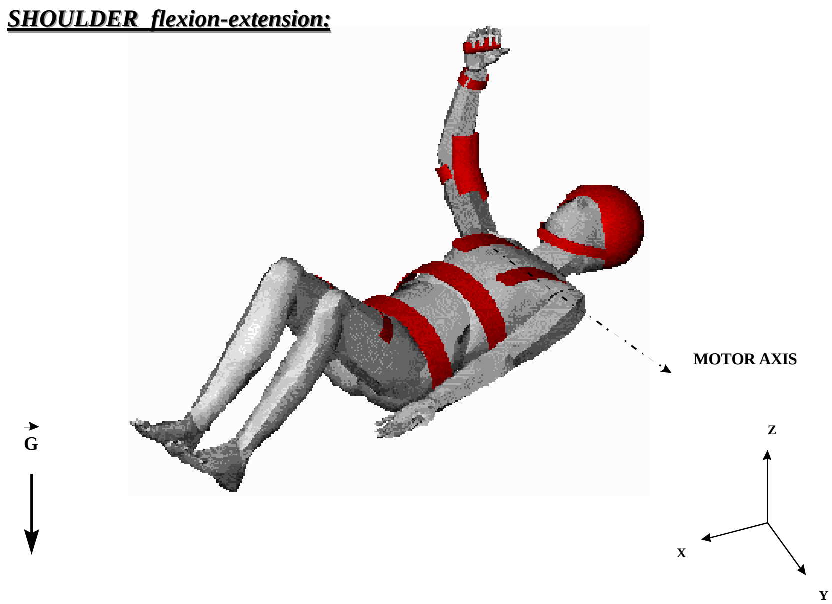


Figure 3.1.2.2.4.2.8 - Shoulder flexion/extension body position.

3.1.2.2.4.2.9 Trunk flexion/extension

Joint	Type of joint	Degree of freedom	Range	Setting	Nominal position
Ankle	Other	**Dorsi-Plantar Flexion**	From -10° to 30° in resting limb	Steps	0°
Ankle	Other	**Eversion-Inversion**	0°	Fixed	0°
Knee	Other	**Flexion-Extension**	80° to 90°	Steps 5°	From 80° to 90°
Knee	Other	**Internal-External Rotation**	From -10° to 10°	Steps	0°
Hip	Other	**Flexion-Extension**	90°	Fixed	90°
Hip	Other	**Abduction - Adduction**	0°	Fixed	0°
Hip	Other	**Internal-External Rotation**	0°	Fixed	0°
Trunk	Main	**Flexion-Extension**	ROM selected with end-stops from 360°	The end positions of ROM are selectable in 2.5° steps	ROM selected with end-stops from 360°
Trunk	Other	**Lateral Right/Left Rotation**	0°	Fixed	0°
Trunk	Other	**Lateral Right/Left Flexion**	0°	Fixed	0°
Wrist	Other	**Pronation-Supination**	not controlled		not controlled
Wrist	Other	**Flexion-Extension**	not controlled		not controlled
Wrist	Other	**Radial-Ulnar Deviation**	not controlled		not controlled
Elbow	Other	**Flexion-Extension**	not controlled		not controlled
Shoulder	Other	**Flexion-Extension**	not controlled		not controlled
Shoulder	Other	**Abduction - Adduction**	not controlled		not controlled
Shoulder	Other	**Rotation**	not controlled		not controlled
Neck	Other	**Flexion-Extension and Right-Left Rotation**	0°	Fixed	0°
G1	Whole body		90°	Fixed	90°
G2	Whole body		-30° to 30°	The end positions of ROM are selectable in 2.5° steps	-30° to 30°

Table 3.1.2.2.4.2.9 **-** *Trunk flexion-extension body position.*

TRUNK flexion-extension :

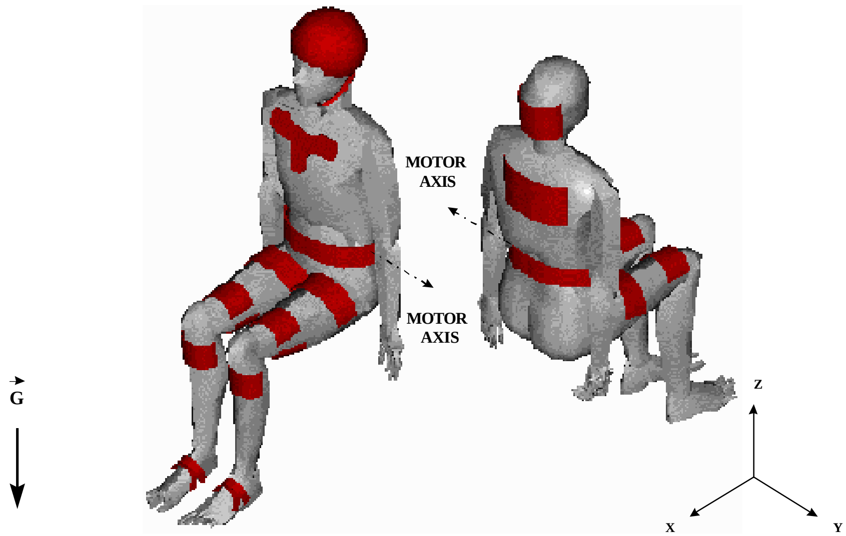


Figure 3.1.2.2.4.2.9 - Trunk flexion-extension body position.

3.1.2.2.4.2.10 Both/one leg press

Joint	Type of joint	Degree of freedom	Range	Setting	Nominal position
Ankle	Main	**Dorsi-Plantar Flexion**	All the angles of ROM are possible	Free	All the angles of ROM are possible
Ankle	Other	**Eversion-Inversion**	0°	Fixed	0°
Knee	Main	**Flexion-Extension**	All the angles of ROM are possible	Free	All the angles of ROM are possible
Knee	Other	**Internal-External Rotation**	From -10° to 10°	Steps	0°
Hip	Main	**Flexion-Extension**	All the angles of ROM are possible	Free	All the angles of ROM are possible
Hip	Secondary	**Abduction - Adduction**	0° to 10°	Continuous	0° to 10°
Hip	Other	**Internal-External Rotation**	0°	Fixed	0°
Trunk	Other	**Flexion-Extension**	0°	Fixed	0°
Trunk	Other	**Lateral Right/Left Rotation**	0°	Fixed	0°
Trunk	Other	**Lateral Right/Left Flexion**	0°	Fixed	0°
Wrist	Other	**Pronation-Supination**	not controlled		not controlled
Wrist	Other	**Flexion-Extension**	not controlled		not controlled
Wrist	Other	**Radial-Ulnar Deviation**	not controlled		not controlled
Elbow	Other	**Flexion-Extension**	not controlled		not controlled
Shoulder	Other	**Flexion-Extension**	not controlled		not controlled
Shoulder	Other	**Abduction - Adduction**	not controlled		not controlled
Shoulder	Other	**Rotation**	not controlled		not controlled
Neck	Other	**Flexion-Extension and Right-Left Rotation**	0°	Fixed	0°
G1	Whole body		90°	Fixed	90°
G2	Whole body		0° to 90°	Fixed	90°
L1	Secondary		90° to 180°	Steps 15°	90° to 180°

Table 3.1.2.2.4.2.10 **-** *Both/one legs pull/press body position***.**

LEG PRESS:

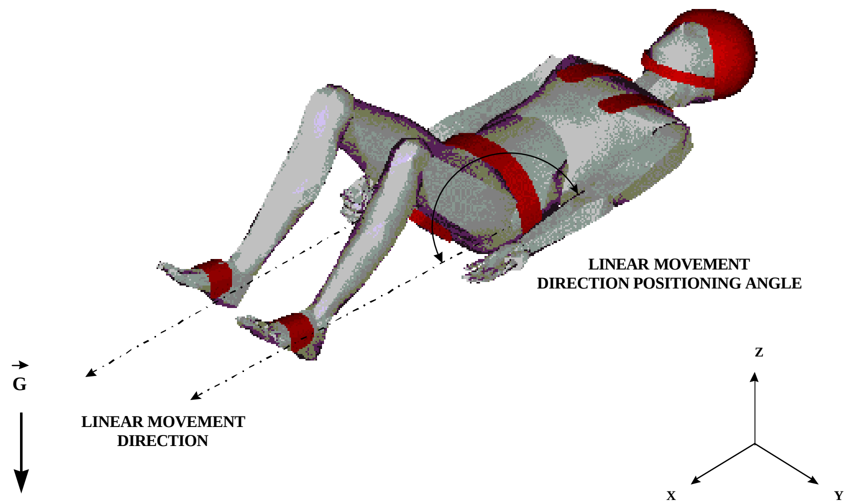


*Figure 3.1.2.2.4.2.10 - Both/one legs pull/press body position***.**

3.1.2.2.4.2.11 Both/one arm press

Joint	Type of joint	Degree of freedom	Range	Setting	Nominal position
Ankle	Other	**Dorsi-Plantar Flexion**	From -10° to 30°	Steps	0°
Ankle	Other	**Eversion-Inversion**	0°	Fixed	0°
Knee	Other	**Flexion-Extension**	From 80° to 90°	Steps	90°
Knee	Other	**Internal-External Rotation**	From -10° to 10°	Steps	0°
Hip	Other	**Flexion-Extension**	50°	Fixed	50°
Hip	Other	**Abduction - Adduction**	0°	Fixed	0°
Hip	Other	**Internal-External Rotation**	0°	Fixed	0°
Trunk	Other	**Flexion-Extension**	0°	Fixed	0°
Trunk	Other	**Lateral Right/Left Rotation**	0°	Fixed	0°
Trunk	Other	**Lateral Right/Left Flexion**	0°	Fixed	0°
Wrist	Other	**Pronation-Supination**	180° or 0°	Fixed	180°
Wrist	Main	**Flexion-Extension**	All the angles of ROM are possible	Free	All the angles of ROM are possible
Wrist	Other	**Radial-Ulnar Deviation**	0°	Fixed	0°
Elbow	Main	**Flexion-Extension**	All the angles of ROM are possible	Free	All the angles of ROM are possible
Shoulder	Main	**Flexion-Extension**	All the angles of ROM are possible	Free	All the angles of ROM are possible
Shoulder	Secondary	**Abduction - Adduction**	0° to 10°	Steps 5°	0° to 10°
Shoulder	Other	**Rotation**	not controlled		not controlled
Neck	Other	**Flexion-Extension and Right-Left Rotation**	0°	Fixed	0°
G1	Whole body		90°	Fixed	90°
G2	Whole body		90°	Fixed	90°
L1	Secondary		0° to 90°	Steps 15°	0° to 90°

Table 3.1.2.2.4.2.11 - Both/one arm pull/press body position

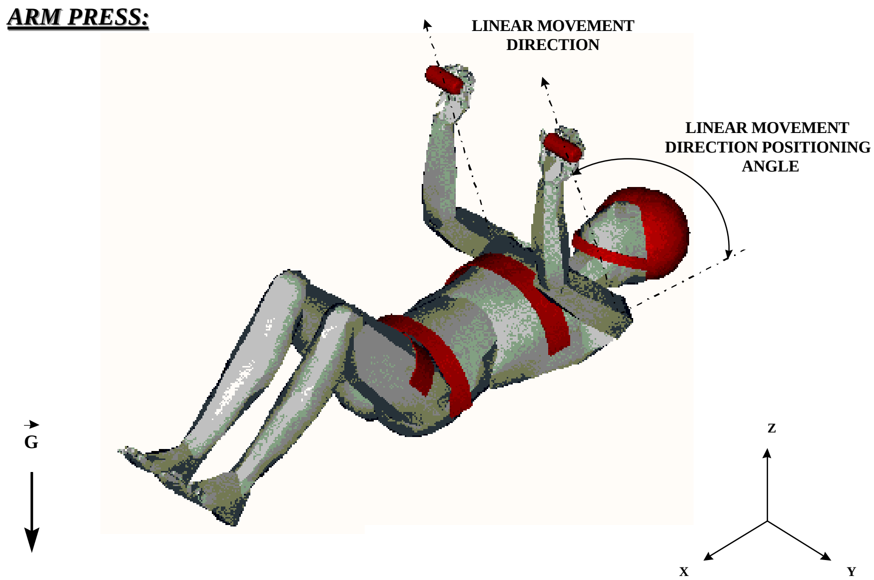


Figure 3.1.2.2.4.2.11 - Both/one arm pull/press body position

3.1.2.2.4.3 Exercise adapters mass and inertia

The moment of inertia and mass of the human adapters, set to fit the largest individual from the supported population, shall not exceed the figures indicated below, in the Table 3.1.2.2.4.3 - Human adapters inertia's.

MOVEMENT	MOMENT OF INERTIA ($Kg\ m^2$)	ADAPTERS MASS (kg)
Ankle dorsi-plantar flexion	0.25	7
Elbow flexion/extension	0.72	6.5
Shoulder flexion/extension	3.2	11
Wrist flexion/extension	0.3	5.5
Knee flexion/extension	0.71	4,5
Hip flexion/extension	4.62	14
Wrist radial/ulnar deviation	0.3	5,5
Wrist pronation/supination	0.3	5.5
Trunk flexion/extension	3	7
Leg / arm press	--	15

External Shaft (from torque sensor till human adapter)	0.1	

Table 3.1.2.2.4.3 - Human adapters inertia's

3.1.2.2.5 Data handling requirements

The MARES shall be able to simultaneously:

- command external device (i.e. PEMS), and
- acquire, temporally store, display, and send to the HRF (workstation or second PCS) for downlink/permanent storage, all MARES related data.

MARES related data shall include:

- Measured data
- Acquired data
- Processed data

3.1.2.2.5.1 Device commanding

MARES shall be able to send pre-programmed Commands and to download Files to external devices via the two Serial interfaces defined in 3.1.5.3.3.1 of this HRD.

MARES shall be able to trigger external devices via the two Trigger Outputs defined in 3.1.5.3.3.6 of this HRD.

MARES shall be able to activate external devices via the two Digital Outputs defined in 3.1.5.3.3.5 of this HRD.

3.1.2.2.5.1.1 Serial Commands

It shall be possible with MARES to create a step in a MARES experiment for independently sending through any of the two Serial interfaces a Command to external devices.

The experiment editor shall allow defining this Command as any predefined string of ASCII characters. The maximum supported length of the string shall be 10 characters.

It shall be possible to program this Command step in the experiment, to optionally wait for the ASCII acknowledgement characters ACK or NAK.

MARES shall react to XON and XOFF ASCII characters received from the external device and, accordingly, stop and proceed with, the transmission through the Serial line.

This commanding shall only be initiated when no MARES Profile is active.

3.1.2.2.5.1.2 Serial Files

It shall be possible with MARES to create a step in a MARES experiment for independently sending through any of the two Serial interfaces a File to external devices.

This File shall be input to MARES GSE, via a 3.5” PC compatible diskette.

This File shall be a PC compatible ASCII text file, with a filename no longer than 8 characters, and with the extension .SER.

The file shall include checksum.

MARES shall have storage capacity to at least store 100 Kbytes of serial Files.

MARES shall be able to accept serial Files of at least 100 Kbytes.

The experiment editor shall allow defining the name of the File to be sent.

It shall be possible to program this Serial File step in the experiment, to optionally wait for the ASCII acknowledgement characters ACK or NAK.

MARES shall react to XON and XOFF ASCII characters received from the external device and, accordingly, stop and proceed with, the transmission through the Serial line.

This File transmission shall only be initiated when no MARES Profile is active.

3.1.2.2.5.1.3 Trigger Outputs

It shall be possible with MARES to independently activate any of the two Trigger signals to external devices, at programmable precise points in time of the MARES Profile.

Time to trigger of external device. It shall be possible to define this point of time of the Trigger edge (**begin**) as a programmable delay from the beginning (Start condition) of any Wait and BMU phase. Fix and random delay times shall be allowed. Both Trigger outputs shall be independently supported.

Start condition of the BMU. The BMU phase shall start upon a programmable trigger condition, which shall be based on comparisons of any of the measured and acquired data, against parameters pre-set before BMU execution. Before this Start condition MARES shall remain in a Wait phase.

It shall be possible to program the Trigger pulses to be either positive or negative, and to have a duration either fixed at 250 µs ± 10 µs, or variable.

It shall be possible to define the **end** pulse condition for the variable pulse duration with the same capabilities defined for the **begin** of the Trigger pulse.

From the moment that the **begin** and **end** conditions occur, MARES shall generate the Trigger edge within 1 ms ± 1 ms.

3.1.2.2.5.1.4 Digital Outputs

It shall be possible with MARES to create a step in a MARES Experiment for independently setting and resetting the two Digital Outputs to an external device.

The commanding of these Digital Outputs shall only be performed when no MARES Profile is active.

3.1.2.2.5.2 Data acquisition

MARES shall create an internal data pool with:

- Measured data
- Acquired data
- Processed data

This data acquisition shall be programmable.

This data acquisition system shall have tools to be able to compensate delays between the different parameters.

3.1.2.2.5.2.1 Measured data

These are all data generated within MARES, excluding Processed data. It shall be possible to select which Measured data are acquired from at least the following groups:

- Scientific parameters, including Shaft Torque/Forces, Velocity, Position.
- Hardware housekeeping, including temperatures, safety status, etc.
- Target waves for BMU control.

3.1.2.2.5.2.2 Acquired data

These are all data acquired from external devices like PSC, PEMS, etc. It shall be possible to select which Acquired data are acquired from at least the following groups:

- via the 8 general purpose analogue inputs,
- via the 2 Trigger Inputs,
- via the 2 Param. Set Inputs,
- via the 2 general-purpose serial line inputs.

3.1.2.2.5.2.2.1 Serial input acquisition

MARES shall be able to acquire at least 32 parameters of 16 bits through each serial interface.

The data will be organised as strings of ASCII characters.

Note: The fixed format of these data strings will be defined by the MARES Contractor in the MARES Interface Specification.

MARES shall use the XON and XOFF ASCII characters as handshake mechanism.

MARES shall be able to support a global continuous acquisition of at least 1 Kbyte/s from all these parameters.

MARES shall internally update these 32 parameters in the parameter pool as data arrive through the serial interface, within 1 second $\pm$ 1 sec. of having received the sample.

Note: The timing for the generation of each of these data strings will be controlled by the external device. Only in cases where continuous acquisition is not a requirement, the user may utilise the Command mechanism for the generation of data strings from within the MARES Experiment.

3.1.2.2.5.2.3 Processed data

These are all data generated by the MARES software, including the data calculated by MARES according to programmable functions, defined by the experimenter:

- Parallel Processing
- Immediate Post-Processing
- Trigger output and Digital Outputs

- software generated, including Experiment variables, internal timers, etc.
- software housekeeping, including Experiment/Profile/BMU step status and identification, general status, etc.
- subject Torque
- etc.

3.1.2.2.5.3 Internal temporal data storage

It shall be possible to perform complete MARES Experiments without having the data connection to HRF. This is the Standalone MARES operation.

During this Standalone operation, MARES shall be able to temporally store all the data to be transmitted to HRF for storage and downlink.

For the worst case global continuous data rate defined in 3.1.2.2.5.5, MARES shall be able to stay in Standalone operation for 1 complete hour.

3.1.2.2.5.4 Data display

MARES Laptop Computer shall be able to display and analyse any of the MARES related data: Measured, Acquired and Processed, with at least the same tools as the tools available in LabView.

These tools shall be programmable at Experiment and BMU levels.

3.1.2.2.5.5 Data transmission to HRF

It shall be possible to program, at MARES Experiment level, which of the Measured and Acquired parameters are to be included in the MARES data packets that will be sent to HRF for storage and downlink, via the Ethernet link.

MARES shall be compatible with LS-71019, Data System Architecture Definition for Human Research Facility.

It shall be possible to program, at MARES BMU level, which time interval of the Measured and Acquired parameters are to be included in the MARES data packets that will be sent to HRF.

The MARES data packets to HRF shall also include the Results of the Processed data, to be able to track on ground the evolution and correct performance of the Experiment.

The term Result of the Processed data covers any data needed on ground to be able to assess whether the MARES processing has been performed correctly or not. The actual derived real-time parameters used to get to these Results do not need to be downlinked if they can be reconstructed with the downlinked data. When data will need reconstruction on ground, the MARES GSE shall be able to reconstruct them.

It shall be possible to program, at MARES Experiment level, the rates of the Measured-Scientific and Acquired (excluding the Serial data) parameters that will be sent to HRF, from at least the following sampling rates: 4000, 2000, 1000, 500, 100, 50, 10, 5 and 1 samples/s.

MARES shall be able to support a global transmission rate for all Measured-Scientific and Acquired parameters of, at least, 35 Ksamples/s, averaged in 1 second.

The Measured and Acquired (excluding the Serial data) parameters shall be transmitted with, at least, 12 bit resolution.

The transmission rate of the received Serial data shall at least be the same as the acquisition rate defined in 3.1.2.2.5.2.2.1 above.

The time correlation (data synchronisation) between the samples of all these parameters shall be better than:

$\pm$ 1 ms for 4, 2, 1 kHz sampling rates

$\pm$ [half of the sampling period] for lower sampling rates

The data samples of any parameter shall be equidistant.

3.1.3 Limit Load Requirements

The MARES shall meet the structural load requirements in 3.1.1.3 of SSP 57000E.

3.1.3.1 Launch/Landing Loads

The MARES, excluding LSA, shall have a first primary natural frequency greater than 35 Hz during launch and landing phases. Evaluation of this requirement shall be based on rigidly mounting the MARES at the Launch Structure Assembly.

The MARES, including LSA, shall be designed to withstand lift-off and landing events. The quasi-static load factors for MARES, excluding LSA, are shown in Table 3.1.3.1 - Preliminary quasi-static load factors. The methodology for combining these loads together with the random load factors, and evaluating lift-off and landing events, shall follow SSP 52005.

LOAD FACTOR DIRECTION	LAUNCH (g's)	LANDING (g's)
X	+/- 7.7	+/- 5.4
Y	+/- 11.6	+/- 7.7
Z	+/- 9.9	+/- 8.8

Table 3.1.3.1 - Preliminary quasi-static load factors

Note: load factors apply concurrently in all possible combinations for each event and the directions correspond to the Orbiter co-ordinate system. 1 g = 9.81 m/s^2.

3.1.3.2 Crew Induced Loads

The MARES shall meet the requirements found in section 3.1.1.3.D and table 3.1.1.3-I of SSP 57000E.

3.1.3.3 Pressure Systems

Not Applicable.

3.1.4 Physical Requirements

3.1.4.1 Mass (WEIGHT)

The total mass of elements 1, 2, 3, 4, 7 and 8, defined below, shall not exceed 200 Kg (approx. 441 lb).

The mass of the following individual elements/groups of elements of MARES shall not exceed the following limits:

1	Main box without Electronic boxes	110 Kg
2	Chair	42 Kg
3	Electronic boxes	42 Kg
4	Vibration isolation frame	11 Kg
5	Linear adapter	16 Kg
6	Rest of adapters	38 Kg
7	External cables	2.5 Kg
8	Rest of flight items	1 Kg

Element 7, External cables, includes the following cables:

- power from Station
- power to laptop
- data to HRF
- data to laptop

Element 8, Rest of flight items, does not include the laptop computer, its support arm nor the LSA.

The elements 1, 2, 3 and 4 will be launched separately.

Elements 1 and 5 will be mounted to the LSA.

Elements 2, 3, 6, 7, and 8 will be stowed in containers.

Element 4 will be either mounted to the LSA or stowed in containers.

3.1.4.2 Envelope

3.1.4.2.1 Stowed envelope

3.1.4.2.1.1 Launch envelope

The total volume of the rectangular envelope containing the different MARES elements/groups of elements shall not exceed the limits defined in Table 3.1.4.2.1.1 - MARES volumes and envelopes, under “Total volume”.

Any individual loose element or item within the listed MARES elements/groups of elements shall not exceed the dimensions in this table, under “Individual item dimensions”.

The extend of groups 7 and 8 in this table is defined in the chapter 3.1.4.1, Mass, of this HRD.

The figures in this table do not include stowage provisions.

Element #	elements/groups of elements	Total volume (dm^3)	Individual item dimensions (mm)
1	Main box (with and without Electronic boxes [3])	280	1030 x 520 x 520
2	Chair	395	1070 x 880 x 420
3	Electronic boxes	60	450 x 300 x 200
4	Vibration isolation frame	21	1051 x 200 x 100
5	Linear adapter	49	1220 x 200 x 200
6ª	Rest of adapters - small	31	300 x 179 x 171
6b	Rest of adapters - long	130	770 x 125 x 70
6c	Rest of adapters - big	21	768 x 500 x 198
7	External cables	10	300 x 300 x 75
8	Rest of flight items	4	300 x 300 x 75

Table 3.1.4.2.1.1 - MARES volumes and envelopes

Elements 1, 2, 4, and 5 will be mounted to the LSA.

Elements 3, 6, 7, and 8 will be stowed in containers.

It shall be possible to stow MARES, for launch only, in the two following combinations of elements, and within their corresponding rectangular envelope(s) (the numbers between brackets [#] correspond to the element numbers in the previous table):

a) **All separately**

Envelopes of each element as in Table 3.1.4.2.1.1 - MARES volumes and envelopes.

b) **Combination [1+5]:** Linear adapter and Main box together

Envelope of [1+5]: 1220 x 720 x 520 mm

Envelope of the rest of the elements as in Table 3.1.4.2.1.1 - MARES volumes and envelopes.

3.1.4.2.1.2 On orbit Stowed envelope

For on orbit stowage MARES will be mounted on the two seat-tracks, either of an ISPR, or of an equivalent structure having the same mechanical interface.

This structure could be located inside an empty ISPR rack space.

To ease the accommodation of MARES inside this limited volume it shall be possible to mount the Main Box on the VIF: either as shown in Fig. 3.1.4.2.1.2-1, or with the Main Box turned 90 degrees.

Alternatively it shall be possible to mount the Main Box to a structure having the same mechanical interface Main Box/VIF.

When stowed on orbit, the envelope of the MARES elements shall still meet the envelope requirements defined in the Table 3.1.4.2.1.1 - MARES volumes and envelopes.

It shall be possible to stow MARES on orbit with the following combinations of elements, and within their corresponding drawn dimensions in mm (the numbers between brackets [#] correspond to the element numbers in the same table):

a) **All separately**

Envelopes of each element as in Table 3.1.4.2.1.1 - MARES volumes and envelopes.

b) **Combination [1+4+7]:** Main box + Vibration isolation frame + cables

Envelope: as per Figure 3.1.4.2.1.2-1 - MARES Stowed envelope [1+4+7]

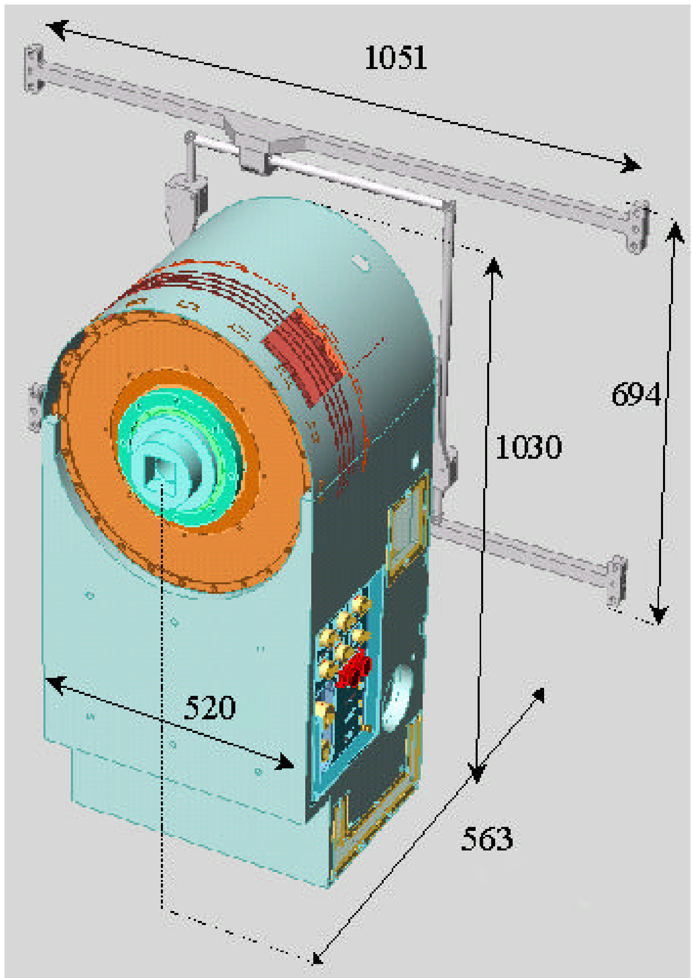


Figure 3.1.4.2.1.2-1 - MARES Stowed envelope [1+4+7]

c) **Combination [1+2+7]:** Main box + chair + cables

Envelope: as per Figure 3.1.4.2.1.2-2 - MARES Stowed envelope [1+2+7].

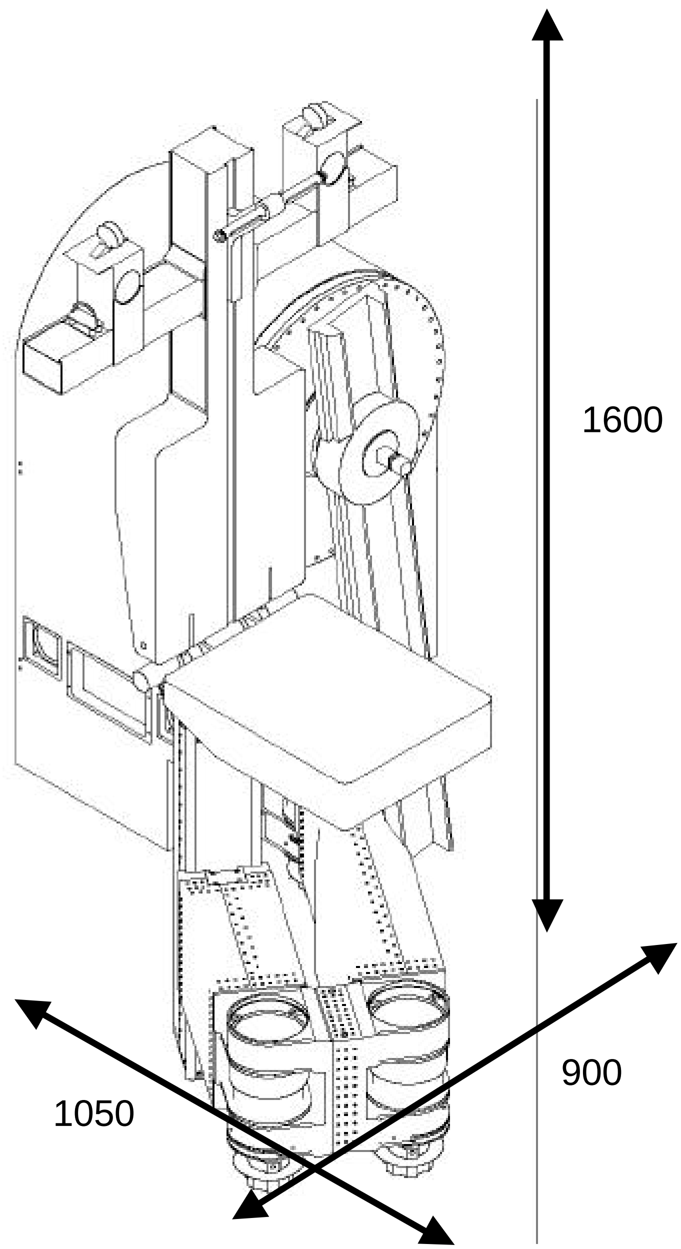


Figure 3.1.4.2.1.2-2 - MARES Stowed envelope [1+2+4+7]

3.1.4.2.2 On orbit Deployed envelope

For normal on orbit operation MARES will be deployed and mounted on the two seat-tracks, either of an ISPR, or of an equivalent structure having the same mechanical interface (see Figure 3.1.4.2.2).

MARES operational envelope shall allow full MARES operation in the US-LAB, COF and JEM modules of the ISS.

Due to ISS module limitations, the only exception to these operational envelope requirement shall be that for Hip exercises, the Main joint (hip) and the Secondary joint (knee) ranges (ROM's) can not be simultaneously met for the whole range of population required:

- 5th - 50th percentile will meet any combination Main/Secundary ranges, and the full female range too;
- 95th percentile male will meet full hip range only for knee ranges 45º-90º;
- 95th percentile male will meet full knee range only for hip ranges 0-70º.

Taking into account these restrictions, the rectangular operational envelope required for the performance of an exercise with MARES shall not exceed the following dimensions (mm):

Exercise	H	W	L	h_{mb}	l_{mb}	Mb
Wrist supination/pronation	1750	1820	1400	1100	600	V
Trunk flexion/extension	1700	1120	2055	1100	870	H
Ankle flexion/extension	1200	1120	2300	975	300	V
Elbow flexion/extension	1300	1750	2100	975	1310	V
Knee flexion/extension	1300	1120	2500	975	800	V
Shoulder flexion/extension	1660	1920	2440	975	1750	V
Hip flexion/extension	2100	1120	2265	975	950	V
Whole leg linear press	1200	1120	2500	975	1450	V
Whole arm linear press	2100	1120	2300	1100	1750	V

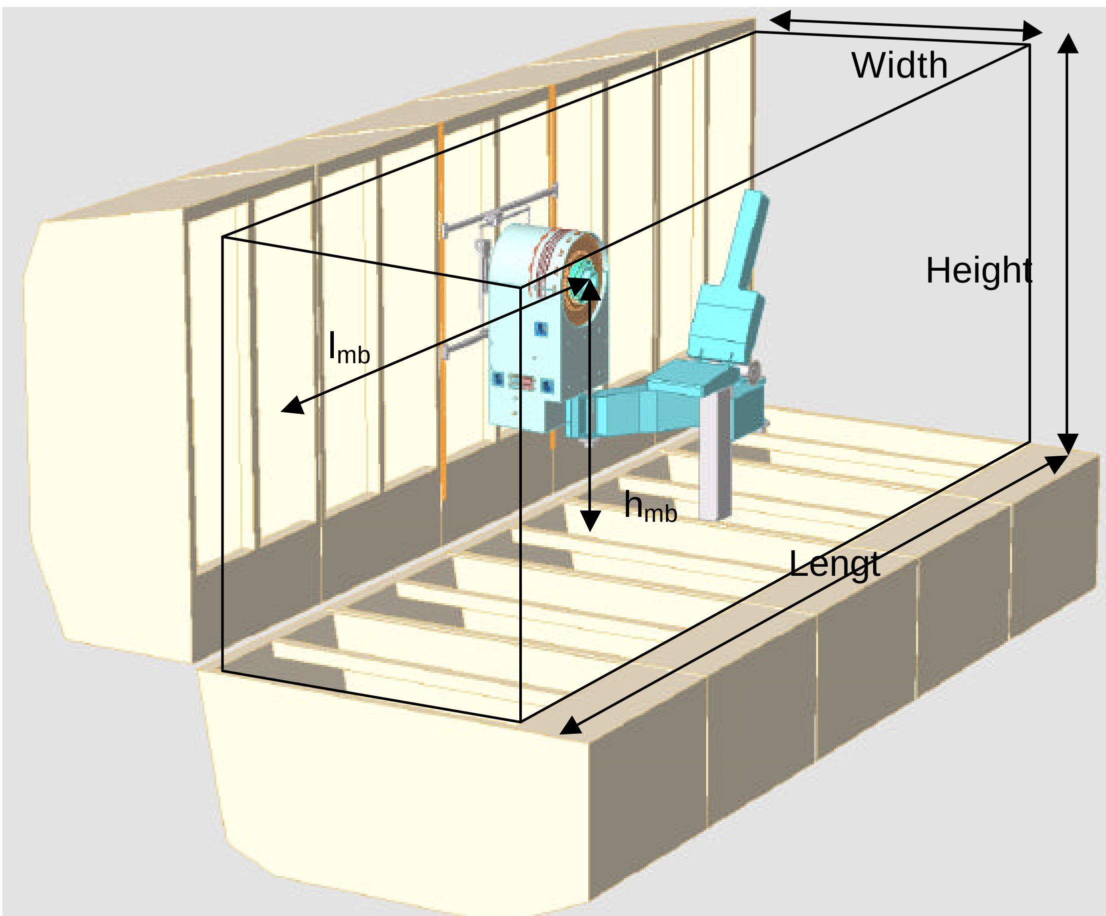
For each exercise, this rectangular envelope shall be measured containing all involved MARES elements and the subject himself, and using the subject nominal position ranges defined in 3.1.2.2.4.2. On the side where MARES attaches to the seat-tracks, the envelope just touches the surface of these seat-tracks. These envelopes shall take into account the necessary displacements introduced by the Vibration Isolation Frame (required to meet the microgravity disturbance requirement).

The Mb column on the previous table defines the Main box orientation. V means the main box is perpendicular to the ISS aisle (as represented in Figure 3.1.4.2.2), and H means the main box is parallel to the ISS aisle.

For information and not as a requirement, the previous table also defines the position of the MARES Main Box motor shaft w.r.t. this rectangular envelope. The dimensions presented correspond to the right extremity exercises. For left extremities, refer the l_{mb} dimension to the distal face of the rectangular envelope instead. This position of the motor shaft is defined when MARES Vibration Isolation Frame is in the neutral position (middle point).

These envelopes shall additionally take into account a required clearance in front of the ISPR Static Envelope (GSE boss plane) of 55 mm (approx. 2.16 inches), except for the Seat-track Entry/Exit envelope specified in the figure 3-32 of the SPP 52000-IDD-ERP.

Note: The clearance of 55 mm has been chosen to allow a certain margin with respect the 1.3



inches protrusion requirement in the ISS.

Figure 3.1.4.2.2 - MARES Deployed configuration

3.1.4.3 Centre of Gravity

The LSA MARES centre of gravity shall be located at:

X = 0mm ± 50mm

Y = -111mm ± 50mm

Z = - 50mm ± 50mm

According to the references given in the following figure.

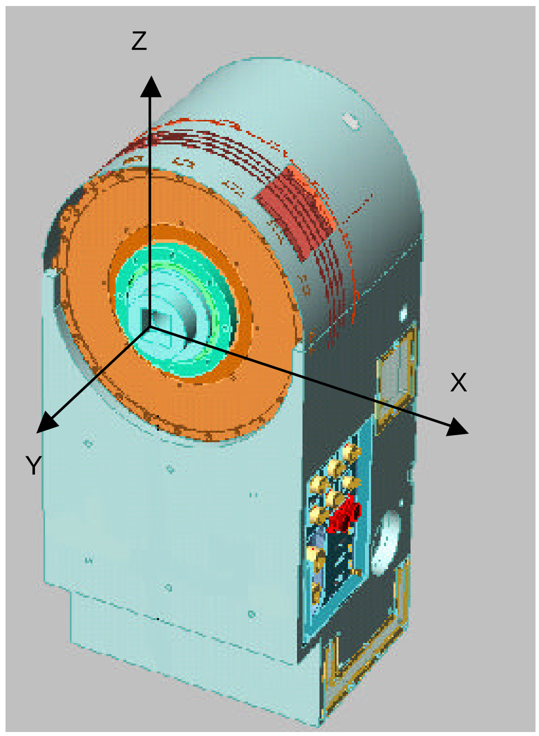


Fig. 3.1.4.3 - Reference axis

3.1.5 Interface

The MARES interfaces with the MPLM (via the MARES LSA) for launch and landing and with the ISPR seat tracks for on orbit deployed and stowed configurations.

MARES interfaces either with ISS UOP or with Center Aisle SUP (COF module) for power, HRF Workstation or second HRF laptop for data communications, external instrumentation like Physiological conditioner (PSC), and Percutaneous Electrical Muscle Stimulator (PEMS) for data acquisition and control.

3.1.5.1 Structural Mechanical Interface Requirements

Section 3.1.5.1.1 specifies the general structural and mechanical requirements for the MARES.

Sections 3.1.5.1.2 to 3.1.5.1.4 delineate the interface requirements for the MARES, specific to the related configuration.

3.1.5.1.1 General Requirements

The structural requirements shall apply to MARES including the Launch Structure Assembly (LSA) for launch and landing, unless otherwise specified.

The structural and mechanical design of MARES shall be compatible with the requirements in section 3.1.1 of SSP 57000E, Pressurized Payloads Interface Requirements Document, during all transportation phases.

3.1.5.1.1.1 Loads

MARES shall meet the load requirements as defined in 3.1.3 of this HRD.

The limit loads specified in this section 3.1.3 of this HRD shall be used to calculate the ultimate loads per the instructions of LS-71012, “Structural Analysis Plan for the Human Research Facility”. A stress analysis shall be done to document that the design has positive margins of safety at all limit loads.

3.1.5.1.1.2 Fracture/Fatigue

The MARES shall be designed to prevent the creation or propagation of any material failures per the requirements of the LS-71010. A fracture control analysis methodology, as defined in SSP52005, shall be done to document that the design does not propagate any material failure due to loading.

3.1.5.1.1.3 Vibration Requirements

The MARES shall be designed to withstand the launch level random vibration environment defined in 5.7 of this HRD, in the launch configurations identified in 3.1.4 of this HRD.

3.1.5.1.1.4 Acoustic Requirements

Refer to section 5.9 of this HRD.

3.1.5.1.1.5 Depressurization Requirements

The MARES shall meet the requirements found in section 3.1.1.2.B of SSP 57000E.

3.1.5.1.1.5.1 Maximum Depressurization/Repressurization Rate

The MARES shall meet the requirements found in section 3.1.1.2.B of SSP 57000E.

3.1.5.1.1.6 Quiescent Period Payload Induced Quasi-steady and Vibratory Accelerations

Forces transmitted by MARES to the station shall not exceed the Vibratory Force spectrum defined in the following figure (the vertical axis presents Newtons force and the ordinates axis Hertz.):

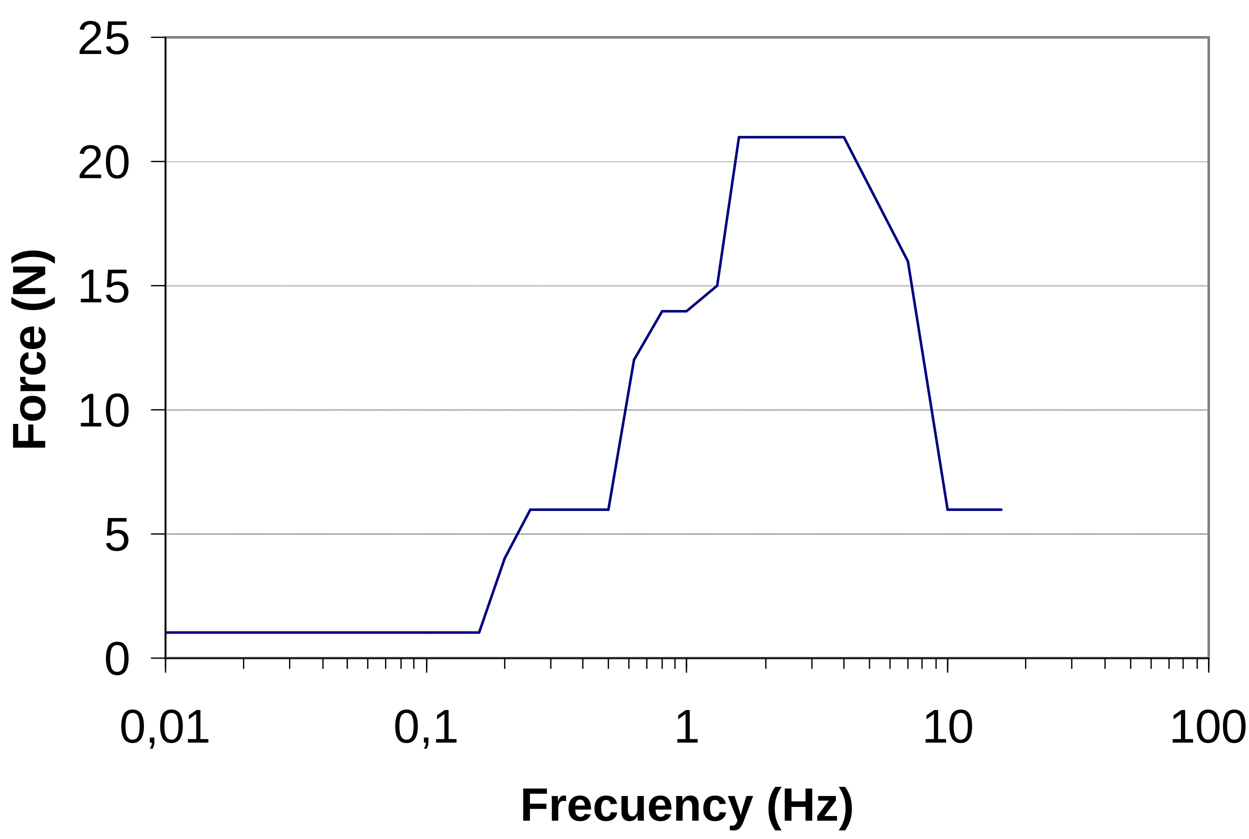


Figure 3.1.5.1.1.6 - MARES RMS resultant forces spectra in any direction

For frequencies between 16 and 25 Hz MARES shall not apply forces higher than 5 N.

For frequencies higher than 25 Hz MARES shall apply only negligible forces with respect to microgravity disturbances.

It shall be a design goal to reduce this spectrum by 50%.

The MARES Vibration Isolation Frame shall only include passive elements.

MARES shall be able to operate properly under the Microgravity Environmental described in Fig. 3.9.4-2 and Fig.3.9.4-4 of the SSP57000E.

The verification of the requirements in this section shall follow the methodology defined in PIRN-57000-0110H. This methodology shall not add additional requirements to MARES.

3.1.5.1.1.7 Quiescent Period Payload Induced Transient Accelerations

The MARES shall limit Transient Accelerations to the Vibratory Force spectrum defined in paragraph 3.1.5.1.1.6 of this HRD.

3.1.5.1.1.8 Payload Installation Requirements

The MARES shall meet the requirements found in section 3.12.1 of SSP57000E.

3.1.5.1.1.9 Ground Environment

The MARES shall meet the Ground Handling requirements found in section 4.11 of this HRD.

Launch/landing requirements

For launch and landing, the MARES elements will interface to the MPLM through the Launch Structure Assembly (LSA), including containers.

Being the LSA an element of MARES its interface to the MARES Main Box is internal, however, since NASA will provide this element, this internal interface is included here.

The MARES shall meet the mass and envelope requirements related to this configuration defined in section 3.1.4 of this HRD.

MARES’ elements/groups of elements will be the following:

Element #	elements/groups of elements	Total volume (dm^3)	Individual item dimensions (mm)
1	Main box (with and without Electronic boxes [3])	280	1030 x 520 x 520
2	Chair	395	1070 x 880 x 420
3	Electronic boxes	60	450 x 300 x 200
4	Vibration isolation frame	21	1051 x 200 x 100
5	Linear adapter	49	1220 x 200 x 200
6[a]	Rest of adapters - small	31	300 x 179 x 171
6b	Rest of adapters - long	130	770 x 125 x 70
6c	Rest of adapters - big	21	768 x 500 x 198
7	External cables	10	300 x 300 x 75
8	Rest of flight items	4	300 x 300 x 75

Table 3.1.5.1.1.9 - MARES elements for launch

Elements 1,2,4 and 5 shall be designed to be structurally mounted to the LSA.

Elements 3, 6, 7, and 8 shall be designed to be stowed in containers.

The structurally mounted MARES elements shall be bolted to a flat surface of the LSA.

The LSA flat surface shall have through holes according to a hole pattern defined by the MARES Contractor in the MARES Interface Specification.

The launch acceleration vector will be parallel to this LSA flat surface.

3.1.5.1.3 On-orbit deployed

When deployed on orbit, MARES will interface either to the two seat-tracks on an ISPR, or to two seat-tracks on a NASA provided structure, which will replicate this ISPR interface dimensions.

The MARES shall meet the mass and envelope requirements related to this configuration defined in section 3.1.4 of this HRD.

MARES shall not apply to the two supporting seat-tracks a force perpendicular to the plane formed by these seat-tracks higher than +/- 2500 N, during any of the foreseen MARES operations, nor due to the Crew applied loads defined in chapter 3.1.3.2 of this HRD.

Under the same circumstances, MARES shall not apply to the two supporting seat-tracks a force parallel to the plane formed by these seat-tracks higher than +/- 1000 N.

Under the same circumstances, MARES shall not apply to the two supporting seat-tracks any torque higher than 160 Nm in any axis.

In the case where the installation is not performed according to the procedures, MARES shall not apply to the two supporting seat-tracks any torque higher than 1200 Nm when two of the fixation elements are removed. This only may happen in short periods during the installation/de-installation of MARES.

3.1.5.1.4 On-orbit stowed

When stowed on orbit, the MARES Main Box (including the Electronic Boxes) together with the Vibration isolation frame (locked), will interface to two seat-tracks having the same interface as the two seat-tracks on an ISPR.

Alternatively it shall be possible to mount the Main Box to a structure having the same mechanical interface Main Box/VIF.

The small MARES elements will be stowed in standard Stowage Trays.

MARES shall comply with the stowage requirements contained in SSP 50018, International Space Station (ISS) Standard Stowage Accommodations Handbook.

The MARES shall meet the mass and envelope requirements related to this configuration defined in section 3.1.4 of this HRD.

In the stowed configuration, MARES shall meet the same requirements defined in 3.1.5.1.3 for the deployed configuration.

3.1.5.2 Electrical Interface Requirements

MARES will be indirectly powered from the ISS UIP interface. Alternatively, MARES could be directly powered either from the ISS Utility Outlet Panel (UOP) or from the Center Aisle SUP (COF module). MARES shall power external devices, like HRF PCS, PEMS, etc.

The following sections delineate the electrical interface requirements for the MARES.

3.1.5.2.1 MARES to UOP and SUP

The MARES will be powered either from a UOP or a SUP.

The MARES shall meet the UOP/SUP requirements in sections 3.2 through 3.2.5.5 of SSP 57000E, with the exception of paragraphs 3.2.2.6, 3.2.4.9 and 3.2.5.4. When SSP 57000E refers to SSP 57001, it refers to SSP57001C (1st November 2000).

Additionally, the UOP/SUP requirements in the following PIRNs to SSP 57000 are applicable to MARES: 57000-NA-0176H, 57000-NA-0198A, 57000-NA-0213, 57000-NA-0222, 57000-NA-0238A, 57000-NA-0246A, and 57000-NA-0254A.

The current through these power lines shall not exceed 10 amps.

For the verification of the related applicable Conducted Susceptibility requirements in 57000E, the methodology defined in tests CS01, CS02 and CS06 (SSP-30238RAC1) shall be followed.

3.1.5.2.2 MARES to HRF PCS

MARES shall provide power to the MARES Laptop Computer.

The MARES Laptop Computer is an element of MARES. Its interface to the MARES Main Box is internal. However, since this element will be the HRF PCS provided by NASA, this internal interface is included here.

The voltage of this power outlet shall be 28 $\pm$ 2 volts under any load up to 2 amps, within the frequency range from 0 to 2 MHz. The output impedance shall not exceed 200 mohms.

At start-up, the output voltage shall not exceed 130% of the nominal voltage (28 V) within the initial 500 ms. After this time the voltage shall be within the nominal limits (+/- 2 V).

MARES shall supply the power to HRF PCS with the current limited at 2 amps.

This power outlet shall be protected in either the OPEN or CLOSE state of the main power switch of MARES, against reverse currents of up to:

- 5 Amps, in pulses of up to 1 ms
- 2.5 Amps, in pulses of up to 10 ms
- 0.15 Amps, in steady-state

This power outlet shall be protected against overloads.

MARES shall supply this power through a connector MS27466T17F6S, with the following pinout:

- Pin #A 28 VDC+
- Pin #B 28 VDC return
- Pin #C chassis ground

3.1.5.2.3 MARES to external devices

MARES shall provide one power outlet for powering external payloads.

The voltage of one of these power outlets shall be 28 volts ± 2 volts under any load up to 2 amps, and with the same characteristics as the outlet defined in 3.1.5.2.2 of this HRD.

3.1.5.2.4 MARES to UIP

MARES will not directly interface to the UIP. However, MARES shall meet the UIP requirements in sections 3.2.1.1.1, 3.2.1.3.1 and 3.2.2.7.1.A-B of SSP 57000E.

Additionally, the UIP requirements in the following PIRNs to SSP 57000 are applicable to MARES: 57000-NA-0176H, 57000-NA-0198A, 57000-NA-0233D and 57000-NA-0238A.

The requirements in 57000-NA-0233D could be verified either by analysis or by test.

3.1.5.3 Command And Data Handling Interface Requirements

The following sections describe the requirements that are applicable for this hardware's design.

3.1.5.3.1 MARES to HRF

For permanent data storage and uplink/downlink, MARES shall interface to HRF either via IEEE 802.3 10-base-T Ethernet or using removable storage media based on the HRF SCSI drivers.

It shall be possible to transmit in realtime to HRF for downlink MARES related data (Measured, Acquired and Processed) during the performance of the MARES Experiment.

MARES shall transmit this data to be downlinked to HRF, using TCP/IP socket protocol, with a maximum throughput of 100 Kbytes/s.

The data packing philosophy shall follow applicable documents LS-40104 and LS-40105. The detailed packet definition will have to be defined in the MARES Interface Specification, subjected to ESA/NASA approval.

It shall be possible to uplink/downlink MARES files (MARES software, MARES Experiments, MARES Protocols, etc.) via the same Ethernet connection and HRF.

MARES shall send and receive these MARES files to/from HRF as an ftp server.

3.1.5.3.2 MARES to HRF PCS

Being the MARES Laptop Computer an element of MARES its interface to the MARES Main Box is internal, however, since this element will be the HRF PCS provided by NASA, this internal interface is included here.

MARES shall interface with the MARES Laptop Computer (HRF PCS) via IEEE 802.3 10-base-T Ethernet.

3.1.5.3.3 MARES to external devices

For interface to other payloads, MARES shall provide general-purpose inputs and outputs of the following types and quantities:

- two Serial lines (1 and 2)
- eight Analogue inputs
- two Parameter Set inputs (1 and 2)

- two Trigger inputs (1 and 2)
- two Trigger output (1 and 2)
- two Digital outputs (1 and 2)

Every one of the above defined lines shall be wired to two separate connectors: one just containing this line, and the other grouping several lines together. This is to make MARES more versatile on adapting to future configurations of external payloads.

There should be at least two individual connectors for each type of line.

The individual Analogue input connectors shall be compatible to the Physiological Signal Conditioner single line connectors.

The individual Serial line connectors shall be compatible to the HRF PCS, ComCard232/422/485/2 PCMCIA card serial line connector, although MARES shall support only a single line at the time, either RS232 or RS422.

The following groups shall be supported:

- 4 Analogue inputs, with the connector being compatible to the 4 lines Physiological Signal Conditioner connector.
- The other 4 Analogue inputs, with the connector being compatible to the 4 lines Physiological Signal Conditioner connector.
- Serial-1, Parameter Set input-1, Trigger input-1, Trigger output-1 and Digital output-1
- Serial-2 and Trigger output-2
- Parameter Set input-2, Trigger input-2 and Digital output-2

The Physiological Signal Conditioner and HRF PCS connectors definition will be available by HRF at MARES PDR.

These interfaces shall have the following electrical characteristics:

3.1.5.3.3.1 Serial lines

Both Serial lines shall include Receive and Transmit channels and both shall be independently configurable to be RS-232 and RS-422 compatible, although not necessarily through the same pin of the connector.

They shall support all standard baudrates and character lengths. The receivers shall be isolated.

3.1.5.3.3.2 Analogue inputs

Type:	analogue, differential input, isolated
Input Range:	+/- 5volts
Input Impedance:	more than 100 Kohm
Input bandwidth:	0 to 2 KHz
Resolution:	12 bits
Sampling Rate:	1 to up to 4 Ksamples/s

3.1.5.3.3.3 Parameter Set inputs

Type:	analogue, differential input, isolated
Input Range:	+/- 5volts
Input Impedance:	more than 100 Kohm
Input bandwidth:	0 to 50 Hz
Resolution:	12 bits
Sampling Rate:	1 to up to 100 samples/s

3.1.5.3.3.4 Trigger inputs

Type:	discrete, differential input, isolated
Electr. character.:	RS-422 compatible

3.1.5.3.3.5 Digital outputs

Type:	discrete, differential output
Electr. character.:	RS-422 compatible

3.1.5.3.3.6 Trigger outputs

Type:	discrete, differential output
Electr. character.:	RS-422 compatible

3.1.5.4 Audio/Video Interface Requirements

Not Applicable.

3.1.5.5 Thermal Control Interface Requirements

3.1.5.5.1 Worst case assumptions

For the determination of the thermal load produced by MARES the following profile, performed by a crew of four members, shall be considered:

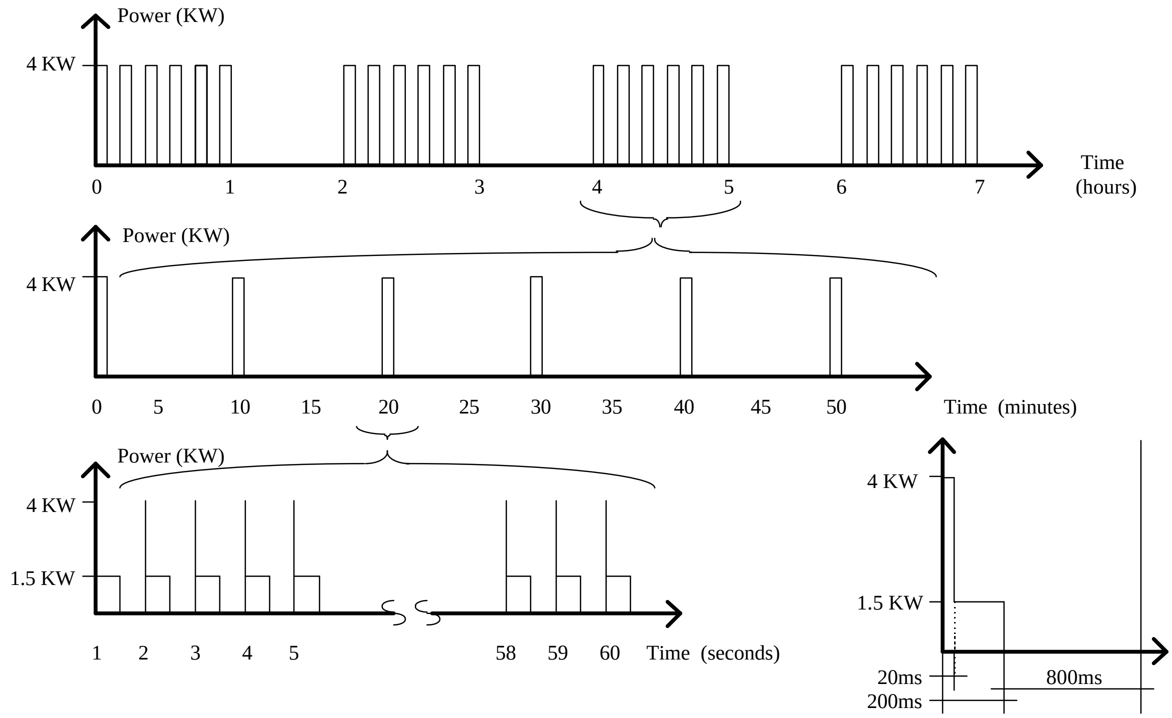


Figure 3.1.5.5.1 - Explosive mechanical power required by an eccentric exercise profile.

This profile corresponds to eccentric exercises performed by each crew member for one hour, doing 60 motions in one minute and then resting for 9 minutes, and repeating this ten minutes exercise 6 times. Each crewmember performs this one-hour exercise once a day, and there is one-hour interval between crewmembers. The complete MARES session takes therefore 7 hours.

3.1.5.5.2 Thermal load

The maximum heat rejection to the station cabin (thermal load) shall be lower than:

- 1000 Watts, when integrated over any one minute
- 350 Watts, when integrated over any one hour
- 200 Watts, when integrated over any eight hours
- 200 Watts, when integrated over any whole day

3.1.5.5.3 Touch Temperature

The MARES shall meet the requirements found in section 3.12.3.2 of SSP 57000E.

3.1.5.5.4 Condensation prevention

The MARES shall meet the requirements found in section 3.9.1.3 of SSP 57000E.

3.1.5.6 Waste Gas Vent and Vacuum Interface Requirements

Not Applicable.

3.1.5.7 Nitrogen Interface Requirements

Not Applicable.

3.1.6 Software Design Requirements

This section contains the main software requirements for the Computer Software Configuration Items (CSCI) associated with the MARES.

The MARES shall additionally comply with the detailed requirements contained in the Mares Payload Software Specifications MARES-SP-007-03-NTE.

3.1.6.1 Definitions

Payload MARES software shall have the following Configuration items:

User Interface software (UIS). Application running on the MARES Laptop Computer providing the interface with the subject/operator for experiment execution, experiment editing, simulation, data processing, etc., and as interface for engineers in maintenance procedures.

Profile Control Unit Software (PCUS). Application running on Profile Control Unit (PCU in MARES Main Box) that co-ordinates MARES electrical subsystems and motor for the performance of movements, acquires parameters, and communicates with UIS and HRF.

3.1.6.2 Modes

It shall be possible to operate MARES in Standalone mode, without data connection to HRF.

It shall be possible to run UIS without connection to PCUS.

3.1.6.3 CSCI #1: User Interface Software (UIS)

3.1.6.3.1 UIS Functional and Performance Requirements

UIS shall be able to perform the main functions listed below:

Main selection of applications :

Experiment editor, Profile editor, Experiment Execution, Display and Post-processing (off-line), Database and PCU window.

Experiment Editor

Experiment editing, modifying, simulating and printing.

Profile Editor

Profile and BMU editing, modifying, simulating and printing.

Experiment Execution

Run of a selected Experiment

Display and Processing

Real-time display of acquired and parallel processing of data during profile execution.

Immediate display and post-processing after the execution of a profile.

Analysis display and post-processing of acquired data off-line.

Communication

Communication with PCUS for profile data, warning message, and MARES data communication.

Database

Crewmember Database files (including editor)

Experiment Database files

Profile Database files

Pattern Database files (Pictures of Adapters, Default text of help, …)

File and folder management between PCU, HRF, PCS and GSE.

Maintenance and Troubleshooting

Housekeeping signals

Troubleshooting

Calibration

3.1.6.3.2 External interface requirements

UIS shall be able to communicate with PCUS through the Ethernet interface via TCP/IP, in a client/server configuration (where the server shall be running on PCUS), in order to receive and send signals, warnings, commands, data and profile parameters.

UIS shall be able to send and receive files (MARES software and Database files) using Network File System through the same Ethernet interface.

UIS shall be able to accept new files (MARES software and Database files) both, via the 3.5" diskette and the CD-ROM drives of the MARES Laptop Computer.

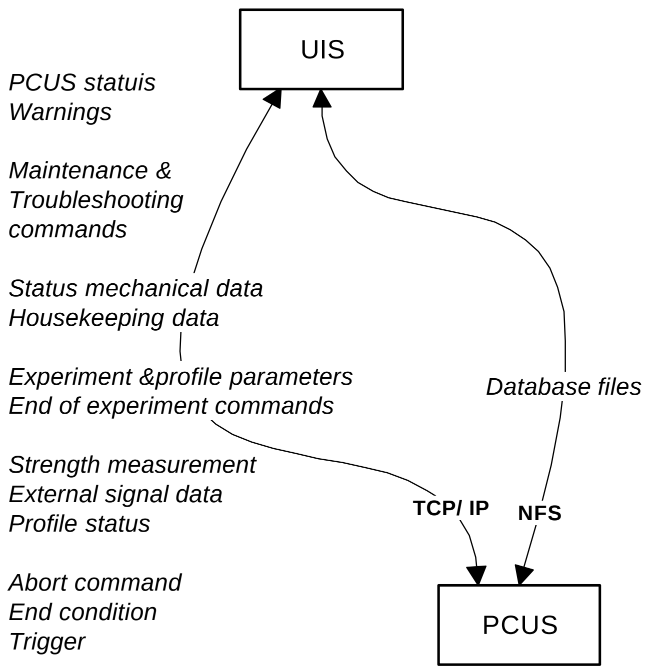


Figure 3.1.6.3.2 - UIS Ethernet interface

3.1.6.3.3 Internal interface requirements

The internal interface requirements will be defined during the software Architectural Design phase.

3.1.6.3.4 Internal data requirements

The internal interface requirements will be defined during the software Architectural Design phase.

3.1.6.3.5 Adaptation requirements

UIS shall be able to adapt to the needs of any experiment with MARES by programming:

- Crew Member Database files
- Experiment Database files
- Profile Database files
- Pattern Database files
- etc.

UIS shall allow the management of all these files.

The procedures generated within MARES will be independent from the in-flight NASA crew procedures. Therefore, there are no compatibility requirements for the MARES Experiment editor.

3.1.6.3.6 Safety requirements

The UIS CSCI shall not be used to hold, store, or process any safety critical parameters or commands.

3.1.6.3.7 Data Privacy requirements

There are no CSCI data privacy requirements for the UIS.

3.1.6.3.8 CSCI environment requirements

UIS shall be able to run on the HRF PCS and on commercial PC’s with equivalent characteristics.

UIS shall be able to run under both: Windows NT and Windows 95 ®.

UIS shall not permanently utilise more than 5 Mbyte of harddisk.

UIS shall not temporally utilise more than 50 Mbytes of harddisk, during MARES operations.

3.1.6.3.9 Software quality factors

The UIS executable shall generate consistent results given the same initial data and conditions.

UIS shall be designed such as to simplify its operation and to minimise the crew time required.

UIS shall be designed such as to simplify its adaptability to a given experiment. The concepts used for the definition of a MARES Experiment and a MARES Profile, shall be straightforward, and well and simply structured.

UIS shall provide easy ways to recover from unintentional operational mistakes.

UIS shall allow easy maintenance of its code.

3.1.6.3.10 Design and Implementation Constraints

The UIS shall comply to the Product Assurance requirements contained in GPQ-010 Issue 1, Revision 0, Product assurance requirements for ESA microgravity projects.

The UIS shall be developed in accordance with the HRF Coding Style Guide in Appendix C of the HRF Software Development Plan (LS-71020).

The MARES software shall comply with Section 13 and with Appendix H (including the reference to other sections there mentioned), of applicable document SSP-50313 (DGCS). In this context, MARES shall be considered as an American payload. Section 4 of Appendix H applies to flight software only.

3.1.6.3.11 Precedence and Criticality of Requirements

All requirements are equally weighted and are not listed in any order of precedence or criticality.

3.1.6.4 CSCI #2: Profile Control Unit Software (PCUS)

3.1.6.4.1 PCUS Functional and Performance Requirements

PCUS shall be able to perform the main functions listed below:

Start up

After hardware reset a boot process performs a test and initialisation of the hardware and stored code. The initial code shall be tolerant to, and be able to recover from, radiation upsets of memory and storage devices.

Warning monitoring

Continuous background monitoring of housekeeping parameters and proper functioning of all elements.

Data acquisition

Acquire and properly time-tag all MARES related data in the MARES data pool.

Commanding

Command internal elements and external payloads according to the programmed MARES Experiments and Profiles.

Communications

Pack data and files according to HRF data formats.

Establish real time and off-line communication links, simultaneously with LAPTOP and HRF for the transfer of status and data.

Establish communication link with external devices (e.g. PEMS) via serial link for commanding and programming.

Establish communication link with UIS via Network file system protocol as remote file access mechanism to exchange MARES files.

Establish communication link with HRF via FTP server to exchange MARES files.

Data archive

All MARES related downlink data shall be temporally archived before downlink to HRF or to GSE.

All MARES files, except downlink data, shall be permanently stored in the PCU.

Maintenance

Maintenance of massive storage device.

Batteries charge procedure.

Calibration procedures.

MARES subsystem troubleshooting.

Execution

Performing the actual MARES experiments.

3.1.6.4.2 External interface requirements

PCUS shall be able to communicate with UIS through an Ethernet interface via TCP/IP, in a client/server configuration (where the server shall be running on PCUS), in order to receive and send signals, warnings, commands, data and profile parameters.

PCUS shall be able to communicate with HRF and GSE through an Ethernet interface via TCP/IP, in a client/server configuration, in order to send all MARES related data for permanent storage and downlink.

The MARES software shall comply with Section 6.3.3 (including the reference to other sections there mentioned), of applicable document LS-71000A, excluding the paragraph related to the Operations Data File Payload (ODF) Display Implementation Plan in 6.3.3.2-D.

PCUS shall be able to send and receive files (MARES software and Database files) using Network File System through both Ethernet interfaces.

PCUS shall be able to interface with the internal MARES hardware elements.

PCUS shall be able to acquire data from, and command, external devices, according to the data handling requirements defined in 3.1.5.3 of this HRD.

The following figure shows PCUS Ethernet communication interfaces.

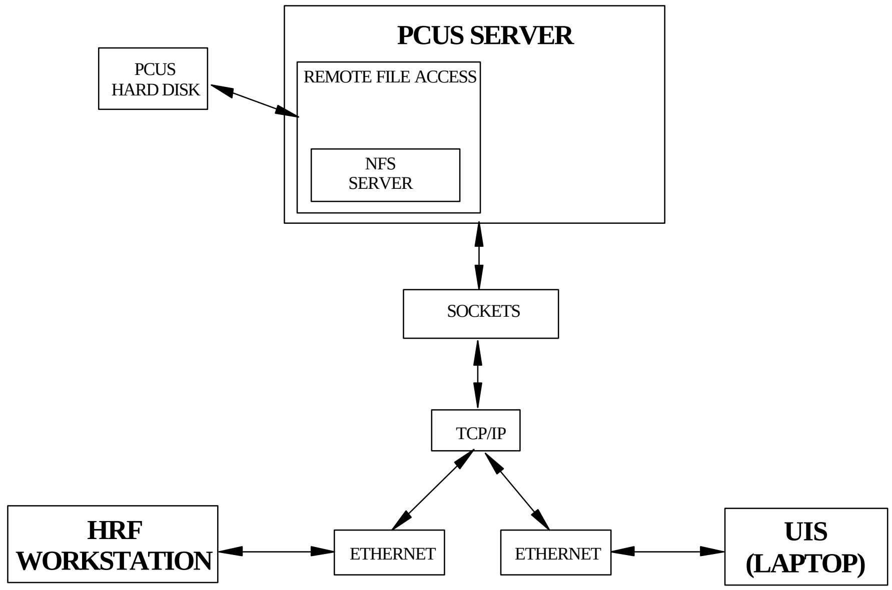


Figure 3.1.6.4.2 - PCUS Ethernet interfaces

3.1.6.4.3 Internal interface requirements

The internal interface requirements will be defined during the software Architectural Design phase.

3.1.6.4.4 Internal data requirements

The internal interface requirements will be defined during the software Architectural Design phase.

3.1.6.4.5 Adaptation requirements

PCUS shall be able to adapt to the needs of any experiment with MARES by programming:

- Crew Member Database files
- Experiment Database files
- Profile Database files
- Pattern Database files

- etc.

PCUS shall allow the management of all these files.

3.1.6.4.6 Safety requirements

The PCUS CSCI shall not be used to hold, store, or process any safety critical parameters or commands.

3.1.6.4.7 Data Privacy requirements

There are no CSCI data privacy requirements for the PCUS.

3.1.6.4.8 CSCI environment requirements

There are no external CSCI environment requirements for the PCUS. The PCU hardware shall be able to support the related MARES requirements.

3.1.6.4.9 Software quality factors

The PCUS executable shall generate consistent results given the same initial data and conditions.

PCUS shall be designed such as to simplify its operation and to minimise the crew time required.

PCUS shall provide easy ways to recover from unintentional operational mistakes.

PCUS shall allow easy maintenance of its code.

3.1.6.4.10 Design and Implementation Constraints

The PCUS shall comply to the Product Assurance requirements contained in GPQ-010 Issue 1, Revision 0, Product assurance requirements for ESA microgravity projects.

3.1.6.4.11 Precedence and Criticality of Requirements

All requirements are equally weighted and are not listed in any order of precedence or criticality.

3.2 MARES GROUND SUPPORT EQUIPMENT (GSE)

3.2.1 Description

Mares' Ground Support Equipment (GSE) includes all ground hardware and software required to support MARES operation.

3.2.2 Performance Requirements

3.2.2.1 FUNCTIONAL REQUIREMENTS

3.2.2.1.1 GSE functions

The MARES Ground Support Equipment shall be developed to perform the following functions:

3.2.2.1.1.1 I & V support

To permit the integration and verification of MARES at the Contractor's site.

3.2.2.1.1.2 Maintenance

To permit the MARES calibration maintenance throughout the MARES programme, if not achievable by means of the MARES element: Calibrator.

3.2.2.1.1.3 Transportation

To permit safe transportation of the MARES.

3.2.2.1.1.4 I/F replacement

To permit stand-alone, full operation and intensive troubleshooting of the MARES post-delivery. From the facility where installed, the MARES GSE shall just require standard electrical main supply and the adequate environment, but it shall not require any of the HRF and ISS interfacing elements.

3.2.2.1.1.5 Adaptation to 1g

To permit the full operation of MARES in 1g conditions, when used in conjunction with all the HRF and ISS interfacing elements, except the HRF PCS and its mounting arm.

3.2.2.1.2 I/F characteristics

The MARES GSE shall provide an accurate simulation of the external interfaces that they replace.

3.2.2.1.3 I/F quality

The quality of the external interfaces of the MARES GSE shall be such as not to degrade the interfaces of potential flight items attached to it. The use of savers or bridging-boxes is recommended.

3.2.2.1.4 Supply of power

All delivered MARES GSE shall be capable of operating from both US (208 Vac 3 phase 60 Hz) and European (400 Vac 3 phase 50 Hz) electrical mains supplies.

3.2.2.1.5 Data storage and analysis

The MARES GSE supporting the 3.2.2.1.1.4 function, shall provide data storage capabilities for at least 10 hours of MARES operation, removable storage media to distribute subsets of this stored data, off-line data analysis and display, and shall be able to generate the flight media where the MARES software will be stored in-orbit. The format of all these media and their contents shall be compatible with standard PC formats.

The off-line data analysis and display mentioned above shall at least cover the MARES display functionality, as defined in 3.1.2.2.5.4, with all MARES related data, as they are defined in 3.1.2.2.5.

3.2.2.1.6 Supplementary equipment

Standard laboratory test and integration tools, as needed by the Contractor during his pre-delivery integration and verification programme (function 3.2.2.1.1) may supplement the MARES GSE. However, all equipment needed to support functions 3.2.2.1.2 through 3.2.2.1.5 above shall be classified as MARES GSE.

4. GENERAL DESIGN REQUIREMENTS

The hardware controlled by this document shall comply with the general requirements stated in this chapter 4. The majority of the requirements in this chapter are derived from SSP 57000. In case of conflict in a particular area between SSP 57000 and this HRD, the HRD requirement shall override the other requirement.

The MARES is a deployable payload of HRF. Unless specifically mentioned otherwise, chapters 4 to 8 only apply to MARES, and not to its GSE.

4.1 HUMAN FACTORS

The capabilities and limitations of a crew person in plain clothes working in International Space Station shall be considered in designing the equipment. The MARES shall comply with the requirements identified in SSP-57000E, "Pressurized Payloads Interface Requirements Document. Those sections identified in the Certification matrix in Appendix A shall be relevant, as specified, to the hardware identified in this HRD.

4.2 MANNED SPACECRAFT CRITERIA AND STANDARDS

The MARES shall be designed to meet the requirements identified in SSP-57000E, "Pressurized Payloads Interface Requirements Document. Those sections identified in the Certification matrix in Appendix A shall be relevant, as specified, to the hardware identified in this HRD.

4.3 BONDING CONTINUITY

Parts shall be bonded to each other per the requirements of SSP-30245 “Space Station Electrical Bonding Requirements” and NSTS 1700.7B ISS Addendum, sections 213 and 220.

MARES shall be bonded to HRF as identified in section 6.3.2.10 of the LS-71000A.

4.4 CLEANLINESS

4.4.1 External Surfaces

The external surfaces of the MARES shall meet the ‘Visibly Clean-Sensitive’ (VC-S) requirements found in document SN-C-0005C, “Contamination Control Requirements for Space Shuttle Program”, as per paragraph 3.11.3 of SSP 57000E. Implementation of the requirement shall be per JHB-5322 "Contamination Control Requirements Manual," and indicated on the hardware top assembly drawings.

4.4.2 Internal Surfaces

The internal parts of the MARES shall meet the VC-S requirements found in document SN-C-0005C, as per paragraph 3.11.3 of SSP 57000E. Implementation of the requirement shall be per JHB-5322 and indicated on the hardware top assembly drawings.

4.4.3 In-flight Cleanliness/Maintenance

The MARES in-flight cleanliness/maintenance is to be controlled through an on-orbit operations procedure. This section is not verifiable.

4.4.4 Fungus Resistant Material

The MARES shall meet the requirements found in paragraph 3.11.4 of SSP 57000E.

4.5 CONSTRUCTION REQUIREMENTS

4.5.1 Materials And Processes

4.5.1.1 General Materials, Processes and Parts Interface

Materials and processes shall meet the requirements of GPQ-010-PSA-101, “Safety and Materials Requirements for ESA Microgravity Payloads”.

Materials and processes shall meet the requirements of NSTS-1700.7B and NSTS-1700.7B ISS Addendum, “Safety Policy and Requirements for Payloads Using the International Space Station”.

4.5.1.2 Stress corrosion

All materials used shall meet the requirements of GPQ-010-PSA-101, “Safety and Materials Requirements for ESA Microgravity Payloads”.

4.5.1.3 Fracture/fatigue

The MARES shall be designed to prevent the creation or propagation of any material failures per the requirements of the LS-71010, “Fracture Control Plan for the Human Research Facility”.

The elements being either in the Safety Critical Structures list, or in the Fracture Critical Structures list, or in both, shall go through a Non Destructive Inspection.

4.5.2 Screw Threads

All straight screw threads shall be in accordance with MIL-S-7742B, "General Specification for Screw Threads Standards, Optimum Selected Series," and/or MIL-S-8879A, "General Specification for Screw Threads, Control of Radius Root With Minor Diameter."

4.5.3 Fasteners

All fasteners shall be purchased with material certification information included in the delivery and placed in a controlled storage facility. Any fastener over the size designation of a number 8 shall be tested per the requirements of either JSC-23642, “JSC Fastener Integrity Program” or ESA PSS-01-746, "General requirement for threaded fasteners".

Due to the extensive use of COTS hardware systems, implementation of this requirement is not absolute, particularly for non-structural members. In these cases, non-adherence must be reviewed with and approved by both, the Agency and the JSC Structures and Mechanics Working Group.

4.5.4 Locking Devices

4.5.4.1 Thread locking adhesive

Any liquid locking substance shall be applied per MIL-S-33540, "General Specification for Liquid Locking Compounds."

4.5.4.2 Lock wire

Not Applicable

4.6 WORKMANSHIP

Workmanship shall be of aerospace quality and shall conform to high-grade aerospace manufacturing practices as directed by GPQ-010, “Product Assurance Requirements for ESA Microgravity Projects”.

4.7 INTERCHANGEABILITY AND REPLACEABILITY

Interchangeability requirements are not applicable to detail parts of permanent assemblies such as welded assemblies or matched detailed parts such as lapped components. Interchangeability requirements do not apply to custom-fitted or custom-sized items.

4.7.1 Interchangeability

All replaceable parts or assemblies having the same part number shall be directly and completely interchangeable with each other, with respect to installation and performance.

4.7.2 Replaceability

Each assembly shall be designed to be replaceable with all other assemblies having the same part number without requiring the replacement of the other assemblies.

4.7.3 Maintainability

4.7.3.1 Maintainability: On-Obit

The MARES shall meet the programmatic maintainability requirements contained in GPQ-010-PSA-102, Reliability and maintainability for ESA microgravity facilities (ISSA), including Change Notice 01.

4.7.3.2 Maintainability: On-Ground

The MARES shall meet the programmatic maintainability requirements contained in GPQ-010-PSA-102, Reliability and maintainability for ESA microgravity facilities (ISSA), including Change Notice 01.

4.8 COLOR

Aluminium parts of MARES hardware shall be anodised turquoise (anodic coating per MIL-A-8625F, type II, class 2, dyed “TURQUOISE”).

For all other parts, the material shall maintain its original color after following cleaning.

4.9 NON-IONIZING CONDUCTED EMISSIONS AND SUSCEPTIBILITY

The MARES shall meet the conducted emissions and susceptibility requirements specified in paragraph 3.2.4.4 of SSP 57000E.

The MARES shall be in accordance with the methodology defined in LS 71016 “Electromagnetic Compatibility Control Plan for the Human Research Facility”.

4.10ILLUMINATION

The MARES shall meet the illumination requirements specified in paragraph 3.12.3.4 of SSP 57000E.

GROUND HANDLING

4.11.1 Ground Handling Load Factors

The MARES and its GSE shall meet the Ground Handling Load Factor requirements included in the table below:

Transportation Environment	Limit Load Factors (g)		
	Longitudinal	Lateral	Vertical
Truck/Road	+/- 3.5	+/- 2.0	- 3.5
			+ 1.5
Barge Water	+/- 5.0	+/- 2.5	+/- 2.5
Dolly/Land	+/- 1.0	+/- 0.75	+/- 2.0
Air Freight	+/- 3.5	+/- 3.5	+/- 3.5

Table 4.11.1 - Limit Load Factors (G) for ground handling, road, air, and barge operations

The choice of hardware shipping/storage containers, procedures, and storage environments can minimise or negate this particular environment’s effect on the hardware. Packaging, handling and shipping shall be in accordance section II.8 of GPQ-010, “Product Assurance Requirements for ESA Microgravity Projects”.

4.11.2 Shock Criteria - Rack Mounted Hardware Only

Not applicable.

4.11.3 Bench Handling - Stowed/Deployed Hardware And Subassembly Only

Not applicable.

4.12 USEFUL LIFE

The useful life of the equipment (equivalent to full life) is the sum of operational life and shelf life. The HRF PRD imposes this requirement. The MARES and GSE useful life shall be a minimum of 10 years.

4.12.1 Operational Life (Cycles)

Operational life applies to any hardware that deteriorates with the accumulation of operating time and/or cycles and thus requires periodic replacement or refurbishment to maintain acceptable operating characteristics. Operational life includes the usage during flight, ground testing, and pre-launch operations. All components of the MARES and GSE shall have an operational life of at least 12.000 hours, evenly spread in a 10 years period, except those identified as having limited life, see Section 4.12.3.

This life limit shall be analysed based on the 7 hours profile defined in section 3.1.5.5.1 of this HRD.

4.12.2 Shelf Life

Shelf life is defined as that period of time during which the components of a system can be stored under controlled conditions and put into service without replacement of parts (beyond servicing and installation of consumable). The MARES and GSE shall have a shelf life of 10 years except those identified as having limited life, see Section 4.12.3

4.12.3 Limited Life

Limited life is defined as the life of a component, subassembly, or assembly that expires prior to the stated useful life in section 4.12 of this HRD. Limited life items or materials, such as soft goods, shall be identified, and number of operations cycles shall be determined. Limited life items shall be tracked on a limited life list that is maintained as a part of the hardware acceptance data pack.

Limited Life items shall be supplemented with enough spares of them, to be able to meet the Operational and Shelf Life requirements.

Spare parts shall comply with the relevant requirements contained in SSP 50018, ISS Standard Stowage Accommodations Handbook.

4.13ELECTRICAL, ELECTRONIC, AND ELECTROMAGNETIC (EEE) PARTS REQUIREMENTS

4.13.1 General Requirements

Parts shall be selected and procured in accordance with GPQ-010, “Product Assurance Requirements for ESA Microgravity Projects” + CN01.

4.13.2 Part Selection

The quality level of parts shall comply with the requirements in V.2.10.2 of GPQ-010, “Product Assurance Requirements for ESA Microgravity Projects” + CN01.

MARES shall be classified as a payload for “manned medium-duration missions”.

In this chapter of GPQ-010, the term “circuits interfacing to the spacecraft elements” shall be interpreted as all parts interfacing with the Station elements, not with HRF.

The term “safety critical circuits” shall be interpreted as all circuits in which a hazardous condition results when a power interrupt device failure allows power to continue to be applied to some payload element.

4.13.3 Cots/Modified Cots

For Commercial, Aviation and Military (CAM) equipment, and for Commercial Off-The-Shelf (COTS) items, the requirements in section IV of GPQ-010-PSA-101, “Safety and Materials Requirements for ESA Microgravity Payloads” apply.

4.14BATTERY REQUIREMENTS

Batteries shall follow the guidelines of JSC-20793 “Manned Space Vehicle Battery Safety Handbook” and must be approved for intended usage by the JSC power systems branch. Batteries shall be two failures tolerant to a catastrophic event. Except for high pressure cells (e.g., nickel hydrogen), batteries are considered sealed containers. Those that contain hazardous fluids shall be leak-before-burst design. All cells in a battery critical for safety or mission success shall be lot certified.

MARES shall follow the control plan in LS-71018, Electrical Power / Battery Control Plan for Human Research Facility.

5. ENVIRONMENTAL DESIGN REQUIREMENTS

5.1 GENERAL

The MARES and GSE shall be designed to meet the performance requirements during and after exposure to the environments specified below. The requirement levels listed below originate from the SSP 57000 section 3.9, except in those cases where certain environments have been established by appropriate JSC test, structural, or thermal organisations. In these cases, the hardware shall meet the requirements so established. The specific method of compliance for each of the following requirements is described in the Certification Matrix found in Appendix A as well as in the appropriate sections below.

5.2 TEMPERATURE RANGES

The MARES shall be safe when exposed to an air temperature range of 36° F (2°C) to 120° F (49°C).

5.2.1 Operating Temperature

The MARES hardware shall be designed to operate at a controlled cabin temperature range (low and high) of 65° F (18° C) to 85° F (30°C).

5.2.2 Non-Operating Temperature

The MARES shall be designed to operate after withstanding an air temperature range of 50° F (10°C) to 115° F (46°C).

5.3 PRESSURE

The MARES shall meet the following pressure requirements:

5.3.1 Operating Pressure

The MARES shall be designed to operate at a controlled cabin pressure range of 13.9 psi (95,8 kPa) to 14.9 psi (103 kPa).

5.3.2 Non-Operating Depressurization

The MARES shall be designed such that a safety hazard will not be created after being exposed to a pressure range of 15.2 to 1.9×10^{-7} psi (103 kPa to $1,3 \times 10^{-3}$ Pa).

5.3.3 Rate Of Change

The MARES shall maintain positive margins of safety for a rate of de-pressurisation equal to 7.75 psi/minute (890 Pa/s), and a re-pressurisation rate of 6.96 psi/min (800 Pa/s).

The hardware shall be designed to operate after exposure to a maximum re-pressurisation rate of 6.96 psi/min (800 Pa/s) and a maximum de-pressurisation rate of 7.75 psi/min (890 Pa/s).

5.4 HUMIDITY

The MARES shall meet the requirements found in section 3.9.1.3 of SSP 57000E.

5.4.1 Deleted

5.4.2 Deleted

5.5 OXYGEN ENVIRONMENT

The MARES shall meet the oxygen environment requirements in SSP 57000E, paragraph 3.9.3.4, i.e. the hardware shall be designed to operate in the controlled oxygen environment of less than or equal to 24.1 % oxygen concentration.

5.6 CONTAMINATION AND WASTE MANAGEMENT

Not Applicable.

5.7 RANDOM VIBRATION

The MARES, excluding the LSA, shall be designed to withstand the launch level random vibration environment specified in the following table:

FREQUENCY	LEVEL
20 Hz 20-70 Hz 70-300 Hz 300-2000 Hz 2000 Hz	0.001 g^2/Hz +9.8 dB/oct 0.06 g^2/Hz -6.5 dB/oct 0.001 g^2/Hz
Composite	5.3 g_{rms}

Table 5.7 - Random Vibration environment for MARES, excluding LSA

5.8 ACCELERATION

Not Applicable.

5.9 ACOUSTIC EMISSION LIMITS

The MARES shall meet the requirements found in section 3.12.3.3 of SSP 57000E.

5.10IONIZING/NON-IONIZING NON-CONDUCTIVE RADIATION

5.10.1 Ionizing

5.10.1.1 Emissions

Not Applicable.

5.10.1.2 Susceptibility

The MARES shall use JSCM Section E22 “Ionizing Radiation Effects” and SSP 30512C “Space Station Ionizing Radiation Design Environment” as design guidelines.

The MARES shall meet the requirements found in section 3.9.3.3 of SSP 57000E.

The MARES shall be able to recover from failures provoked by the ionizing radiation environment defined in section 3.9.3.3 of SSP 57000E.

The MARES software shall include measures to recover from SEU/latch up.

5.10.2 Non Ionizing

5.10.2.1 Emission

The MARES shall meet the radiated emissions requirements specified in paragraph 3.2.4.4 of SSP 57000E.

The **MARES** shall be in accordance with the methodology defined in LS 71016 “Electromagnetic Compatibility Control Plan for the Human Research Facility”.

5.10.2.2 Susceptibility

The MARES shall meet the radiated susceptibility requirements specified in paragraph 3.2.4.4 of SSP 57000E.

The **MARES** shall be in accordance with the methodology defined in LS 71016 “Electromagnetic Compatibility Control Plan for the Human Research Facility”.

5.11CORONA

The MARES shall meet the requirements found in section 3.2.4.8 and 4.3.2.4.8 of SSP 57000E.

6. ENVIRONMENTAL ACCEPTANCE TEST REQUIREMENTS

All MARES flight hardware elements under the Contractor's responsibility shall be exposed to environmental acceptance tests to verify workmanship and manufacturing and assembly conformance to drawings.

6.1 ACCEPTANCE VIBRATION TEST

All flight and qualification units shall be tested to the acceptance level random vibration environment specified in Table 6.1 - Acceptance level random vibration environment, to verify that the unit was properly assembled per drawings and procedures.

FREQUENCY	LEVEL
20 Hz 20-80 Hz 80-350 Hz 350-2000 Hz 2000 Hz	0.010 g^2/Hz +3.0 dB/oct 0.04 g^2/Hz -3.0 dB/oct 0.007 g^2/Hz
Composite	6.1 g_{rms}

Table 6.1 - Acceptance level random vibration environment

The vibration test shall be for 60 seconds for all three axes.

The test adapter shall be designed to achieve an input tolerance of +/- 1.5 dB for the whole frequency range.

A full functional must be performed before and after the Acceptance Vibration Test. An abbreviated functional must be performed after each axis has been tested.

Low-level sine sweeps are to be performed before and after random tests, for each axis.

6.2 ACCEPTANCE THERMAL CYCLE TEST

The hardware shall be designed to withstand a thermal cycle test. The test level shall be developed based upon the limitation of the hardware (especially if COTS are included). The hardware shall be exposed to the acceptance test defined in 5.4.1.1.6.2 of LS-71000A.

7. QUALIFICATION TEST REQUIREMENTS

The following sections list the qualification testing levels for several of the natural environments listed in section five (5) of this HRD. This information shall be included in the comments column of the Certification matrix in Appendix A.

All MARES hardware elements under the Contractor's responsibility of the Qualification model shall be exposed to environmental qualification tests.

7.1 QUALIFICATION RANDOM VIBRATION TEST

The MARES shall be tested to the qualification acceptance level random vibration environment specified in Table 7.1 - Qualification acceptance level random vibration.

FREQUENCY	LEVEL
20 Hz 20-80 Hz 80-250 Hz 250-2000 Hz 2000 Hz	0.017 g^2/Hz +3.0 dB/oct 0.067 g^2/Hz -3.0 dB/oct 0.012 g^2/Hz
Composite	7.9 g_{rms}

Table 7.1 - Qualification acceptance level random vibration

The vibration test shall be for 120 seconds for each of the three axes.

A full functional must be performed before and after the Qualification Acceptance Vibration Test (QAVT). An abbreviated functional must be performed after each axis has been tested.

Successful completion of the QAVT will certify hardware for two modifications/re-acceptance test. Certification for each additional modification requires an additional 60 seconds of QAVT.

7.2 QUALIFICATION THERMAL CYCLE TEST

The MARES shall be designed to withstand a thermal cycle test. The test level shall be developed based upon the limitation of the hardware (especially if COTS are included).

The hardware shall be exposed to the qualification test defined in 5.4.1.1.6.1 of LS-71000A.

8. PRODUCT ASSURANCE AND SAFETY

8.1 GENERAL REQUIREMENTS

The MARES hardware shall comply with the design requirements contained in the following PA and safety requirements documents:

- GPQ-010 and CN01

  Product Assurance Requirements for ESA Microgravity Projects.

- GPQ-010-PSA-101

  Safety and Materials Requirements for ESA Microgravity Projects.

- GPQ-010-PSA-102 and CN01

  Reliability and maintainability for ESA microgravity facilities (ISSA)

EEE components requirements in GPQ-010 do not apply to the MARES GSE.

The document “Technical PA/Safety Requirements for Payloads for the International Space Station Alpha” (MS-ESA-RQ-027), called as applicable by GPQ-010-PSA-101, shall not be considered as applicable to the MARES project.

For information, TSS 30595 will be replaced by NSTS 13830 rev. C, when this new document will be available, in defining the Safety Reviews plan. The Contractor shall use, as reference, the HRF plan for conducting Safety contained in LS-71002, HRF System Safety Program Plan for the Human Research Facility.

The interpretations to the safety requirements that can be found in NSTS/ISS 18798B, Interpretations of NSTS/ISS Payload Safety Requirements, are also applicable to the MARES.

8.2 Fire prevention requirements

MARES shall comply with the Fire Detection and Suppression requirements contained in the SSP 57000E, sections 3.1.1.4K, 3.10.1, 3.10.3.1A and B, 3.10.3.2, 3.10.3.3 and 3.10.4A.

In case MARES needs to actively monitor its elements for Fire protection, MARES may use the Ethernet connection to HRF for this purpose, instead of the MIL-STD 1553 bus. HRF will be kept active and convert the information to this 1553 bus.

APPENDIX A

MUSCLE ATROPHY RESEARCH AND EXERCISE SYSTEM (MARES)

CERTIFICATION MATRIX